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Survival rates of ultra-short (<6 mm) compared with short locking-taper implants supporting single crowns in posterior areas: A 5-year retrospective study

Giorgio Lombardo MD[1] | Annarita Signoriello DDS[1] | Mauro Marincola DDS[2] | Pietro Liboni DDS[1] | Estevam A. Bonfante DDS[3] | Pier F. Nocini MD[1]

[1]Department of Surgery, Dentistry, Paediatrics and Gynaecology (DIPSCOMI), School of Dentistry, University of Verona, Verona, Italy

[2]Research Department, Dental Implant Unit, Faculty of Dentistry, University of Cartagena, Cartagena, Colombia

[3]Department of Prosthodontics and Periodontology, Bauru School of Dentistry, University of Sao Paulo, Bauru, Brazil

Correspondence
Annarita Signoriello, Department of Surgery, Dentistry, Paediatrics and Gynaecology (DIPSCOMI), School of Dentistry, University of Verona, Piazzale L.A. Scuro 10, 37134 Verona, Italy.
Email: annarita.signoriello@univr.it

Abstract

Background: Short and ultra-short implants represent a predictable treatment, in terms of implant survival, with patients presenting insufficient available bone volumes. Moreover, single crown restorations represent a gold standard in terms of oral hygiene.

Purpose: The aim of this retrospective study was to evaluate implant survival, marginal bone loss, and peri-implant complications in 333 locking-taper short and ultra-short implants.

Materials and Methods: Implants were placed in the maxillary and mandibular posterior regions of 142 patients. Clinical and radiographic examinations were performed at 5-year recall appointments.

Results: All implants placed consisted of 8.0-, 6.0-, and 5.0-mm length, 38.14%, 34.53%, and 27.33%, respectively. Three hundred thirty-two implants (one early failure) were rehabilitated with single crowns in 141 patients. In 45.48% of the implants the crown-to-implant ratio was ≥2, with a mean value of 1.94. Overall implant-based survival after 5 years of follow-up was 96.10%: 96.85%, 95.65%, and 95.60% for 8.0-, 6.0-, and 5.0-mm length implants, respectively ($p = 0.82$). Overall patient-based survival was 91.55%. Regarding crestal bone level variations, average crestal bone loss and apical shift of the "first bone-to-implant contact point" position were 0.69 and 0.01 mm, respectively. Setting the threshold for excessive bone loss at 1 mm, during the time interval from loading to follow-up, 28 implants experienced loss of supporting bone greater than 1 mm: 19 of them (67.85%) were surgically treated with a codified surgical regenerative protocol. After 60 months, a peri-implantitis prevalence of 5.94% was reported, with an overall implant success of 94.06%: 95.93%, 92.73%, and 93.10% for 8.0-, 6.0-, and 5.0-mm length implants, respectively ($p = 0.55$).

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Conclusion: Long-term outcomes suggest that short and ultra-short locking-taper implants can be successfully restored with single crowns in the posterior area of the maxilla and mandible.

KEYWORDS

bone loss, crown-to-implant ratio, peri-implantitis, short, single crown, success, survival, ultra-short

What is known

Recent studies support the use of short (lengths ≥6 and ≤8 mm) implants as a predictable method of rehabilitation in posterior regions only if splinted. Moreover, most of the studies reported follow-ups of less than 5 years, with the absence of a specific assessment of different types of implant design.

What this study adds

This retrospective study reports promising 5-year outcomes in terms of implants survival for short and ultra-short implants with a plateau design, a locking-taper implant-abutment connection and restored with single crowns.

1 | INTRODUCTION

In the last decades implant placement has become a widespread and predictable methodology of treatment for partially edentulous posterior regions. However, in some instances the long-term absence of teeth has resulted in extensive resorption of the alveolar ridge.[1] As a consequence, there may not be a sufficient volume of bone available for standard implant rehabilitation without subjecting the patient to difficult, invasive, and costly surgical grafting procedures.[2] In these specific conditions, the placement of short (lengths ≥6 and ≤8 mm) implants[3] may represent a valid alternative therapy to augmentation procedures for maxillary and mandibular jaw atrophies. Moreover, the use of short implants reduces the number of surgeries, potential morbidity, and time and costs of the treatment. Several meta-analyses showed no significant differences in survival rates between short and standard diameter implants.[4–7] With a better understanding of the mechanisms underlying osseointegration and the development of new technologies, consisting in modifications of implant surfaces[8] (through traditional methods[9] or bioactive components[10]) and improvement of macrodesign features,[11,12] short implants have shown high-quality performances.

The success of short implants has led to the development of a new class of implants, ultra-short implants (length < 6 mm).[13] Recent meta-analyses and systematic reviews focusing on implants with lengths ≤6 mm[14–19] have supported the use of these implants as a predictable method with stable results, but most of the studies reported follow-ups of less than 5 years. Moreover, most of them combined splinted crown and single-crown restorations[2,4–7,20,21]: the absence of a specific assessment of different types of restoration design may certainly represent a serious limitation in reaching effective conclusions regarding the survival and success of ultra-short implants.

In a previous investigation,[22] short implants were used to restore multiple adjacent teeth loss with unsplinted single crowns, which may be suggested as a gold standard in terms of oral hygiene procedures and framework. On the other hand, the analysis of implant survival and success has been strictly connected with peri-implant marginal bone loss, a critical issue in the case of unsplinted prosthetic rehabilitations characterized by disproportionate crown-to-implant ratios (CIRs).[23] Authors of the present study support the hypothesis that these issues are of particular importance in case of ultra-short implants, as the stability of marginal bone levels appears to be of crucial importance for implant survival at the medium and long-term follow-ups. Despite discrepancies among different authors regarding the definitions of marginal bone loss and success criteria[22,24–27] in the evaluation of short and ultra-short locking-taper implants, the threshold for bone loss compatible with implant success was set at 1 mm after 5 years. This rigorous value was proposed considering that a threshold of 2 mm after a medium-term follow-up, even if allowable for 8-mm length implants, cannot be considered acceptable for 6.0- and 5.0-mm length implants (the shortest groups), for the involvement, in terms of marginal bone loss, of almost half of implant length.

Given the limits of previously published investigations (especially short-term 3-year follow-up), and since controversial outcomes are still present in the literature for ultra-short implants supporting single crown restorations,[5,28–30] the aim of this retrospective study was to evaluate whether the clinical and radiographic results of ultra-short (5-mm length) locking-taper implants supporting single crowns are comparable to short implants (6- and 8-mm length) after 5 years of follow-up.

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2 | MATERIALS AND METHODS

A retrospective study with a 5-year follow-up was conducted in 2020 on patients who had been referred between February 2007 and June 2015, for edentulism (tooth loss caused by trauma, caries or periodontal disease) in the posterior areas of maxilla and mandible at the Dental and Maxillo-Facial Surgery Clinic at the University of Verona. The study was approved by the University Institutional Review Board (Prot. 34 939, CROWNMAXMAND, 30/05/18). The nature and aim of the study, together with the anonymity in the scientific use of data, were clearly presented in a written informed consent form, and signed by every patient. All procedures accorded with Helsinki Declaration and good clinical practice guidelines for research on human beings.

Patients enrolled for the study matched the following inclusion criteria[22,31–33]: aged between 18 and 90 years; having had single-tooth replacement of at least one 8.0, 6.0, or 5.0 mm locking-taper implant supporting a single crown; had no previous consent for bone augmentation procedures; had a history of treated chronic periodontal diseases, or were never affected by any form of periodontal disease; and who were compliant with a regular maintenance program (professional oral hygiene sessions every 4 months). Exclusion criteria of the study were previously described[22,31–33] (see Appendix).

The locking-taper (Morse taper or Morse cone) dental implant system (Bicon Dental Implants; Bicon LLC) used in this study is characterized by a convergent crest module, platform switching, plateau root-form design, and an Integra CP surface (hydroxyapatite treated and acid-etched).[22,31–33]

All surgical treatments were conducted by a single clinician, as previously described[22,31–33] (see Appendix). After 4–6 months the implants were surgically uncovered, healing abutments were placed, and the mucosal flaps readapted around them. After 3 weeks of soft-tissue healing, impressions were taken using a polyether material (3M ESPE Impregum Impression Material). Definitive single-crown porcelain or composite restorations were placed within 2 weeks. The choice for restorative materials (porcelain or composite) was based on patients' preference, which was guided by personal economic resources in most of the cases (see Appendix). The technique used for the composite restorations was the Integrated Abutment Crown (IAC), in which crowns are conventionally fabricated but also extraorally cemented to the abutment, excess cement is removed and then the one-piece abutment and crown are inserted (see Appendix).[34]

Recall appointments were established to manage prosthetic complications as needed, and a maintenance program was designed to provide patients a professional oral hygiene session every 4 months. Clinical and radiographic examinations[22,31–33] were performed during the follow-up 5 years from loading time, one time per year at regular intervals.

The postsurgery evaluations and the follow-up evaluations were performed by two other operators both of whom were different from the clinician who performed the surgical phase.

Implant lengths considered in the study were 8.0, 6.0, and 5.0 mm; implant diameters were 3, 3.5, 4.0, 4.5, 5.0, 6.0, and 6.5 mm. Covariates included were: sex, age, smoking history, history of periodontal disease[35] (see Appendix), American Society of Anesthesiologists (ASA) status, number of oral hygiene sessions per year, use of interproximal oral hygiene devices, arch involved, tooth site, prosthetic material, CIR.[22,31–33]

Study outcomes were implant survival, marginal bone loss, and implant success after 5 years of follow-up, which were assessed according to covariates. In regard with implant survival, failure was considered as the need for implant removal either before loading (due to absence of osseointegration), or after loading (due to excessive bone loss). Implant survival was considered as the implant's state of being in function at the 5-year follow-up evaluation, for example, symptom-free, without mobility, radiolucency, or bone loss so severe as to warrant implant removal.[33,36–38]

A descriptive analysis was conducted between loading time and the 5-year follow-up time, according to covariates. This included assessment of crestal bone level (CBL; average bone level around implants at mesial and distal sides, expressed in mm), first bone-to-implant contact (F-BIC; in mm)[39–41] with their variations ΔCBL (average bone loss) and ΔF-BIC (average apical shift of the "first bone-to-implant contact point" position) (see Appendix).

Peri-implant soft tissues were assessed using a periodontal probe (Florida Probe; Florida Probes Company) and applying a force of mild intensity (0.25 N). For each implant site, four parameters were assessed. The Modified Bleeding Index (mBI), and the Modified Plaque Index (mPLI), as reported in the literature by Mombelli,[27] were used to record the appropriate values for the mesial, central, and distal on the buccal and lingual/palatal sides of each implant. Similarly, the peri-implant probing depths (PPD) were performed on the same six sites. The amount of keratinized tissue (KT) was assessed by measuring the distance between the zenith of the buccal gingival margin and the mucogingival line.

Biological complications after loading were also assessed at the 5-year recall appointment. According to the latest updates,[42] peri-implant mucositis was defined as at least one soft-tissue peri-implant surface with positive BOP or pus on probing, PPD ≥4 mm, and no radiographically detectable bone loss. It should be noted that visual signs of inflammation can vary and that peri-implant mucositis can exist around implants with variable levels of bone support.[35] We diagnosed peri-implantitis when an implant had simultaneously one surface with positive BOP or pus on probing, increasing PPD compared to previous examinations or PPD ≥5 mm in the absence of the previous examination data, and presence of radiographically detectable bone loss greater than 1 mm when compared with the loading measurements. As opposed to earlier 3-year studies on locking-taper implants, the threshold for bone loss at a longer follow-up of 5 years was set at 1 mm. This was done in recognition of the fact that in the present study implant length was highly reduced compared to other

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longer implant types, for which a threshold of 2 mm can be considered acceptable.[35,42] In case of 6.0- and 5.0-mm length implants, a marginal bone loss of 2 mm, representing slightly less than half of the entire implant length, appears to be underestimated after 5 years of follow-up.

Implant success was defined according to the following criteria[43,44] and to the defined bone loss threshold: absence of persistent pain, dysesthesia, or paraesthesia in the implant area; absence of peri-implant infection with or without suppuration; absence of perceptible mobility of the implant; and finally, absence of persistent

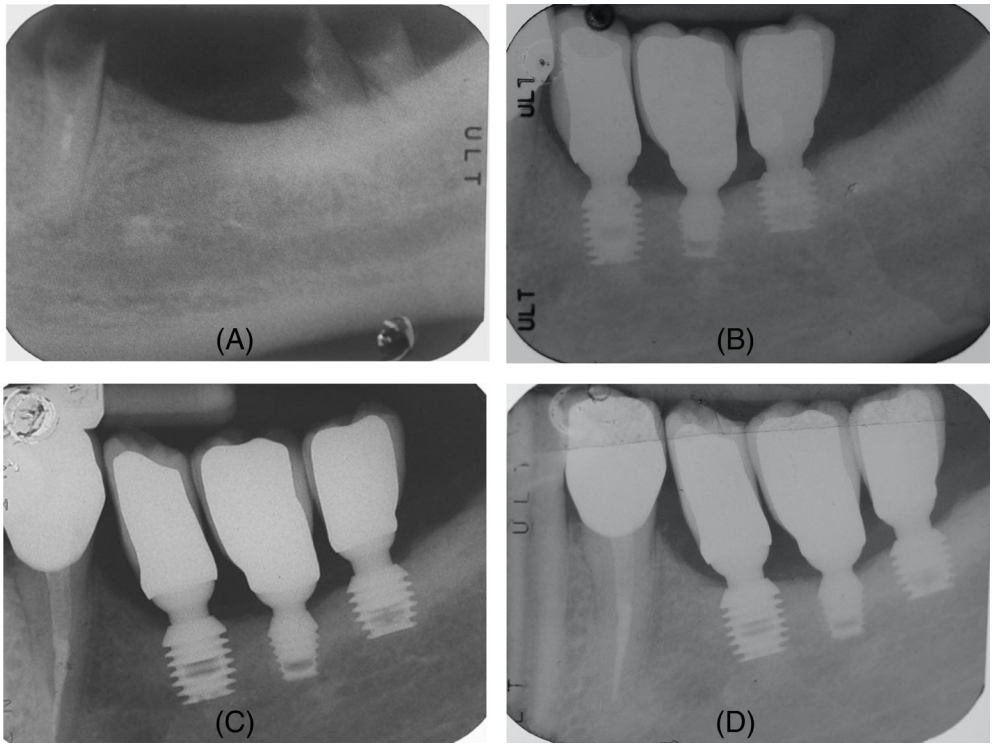

FIGURE 1 Single implants placed in 3.4, 3.5, and 3.6 sites (5 × 6 mm, 4 × 5 mm, 5 × 5 mm): (A) Preoperative radiograph before implants placement; (B) radiograph obtained at time of loading; (C) radiograph obtained at 3-year follow-up; (D) radiograph obtained at 5-year follow-up

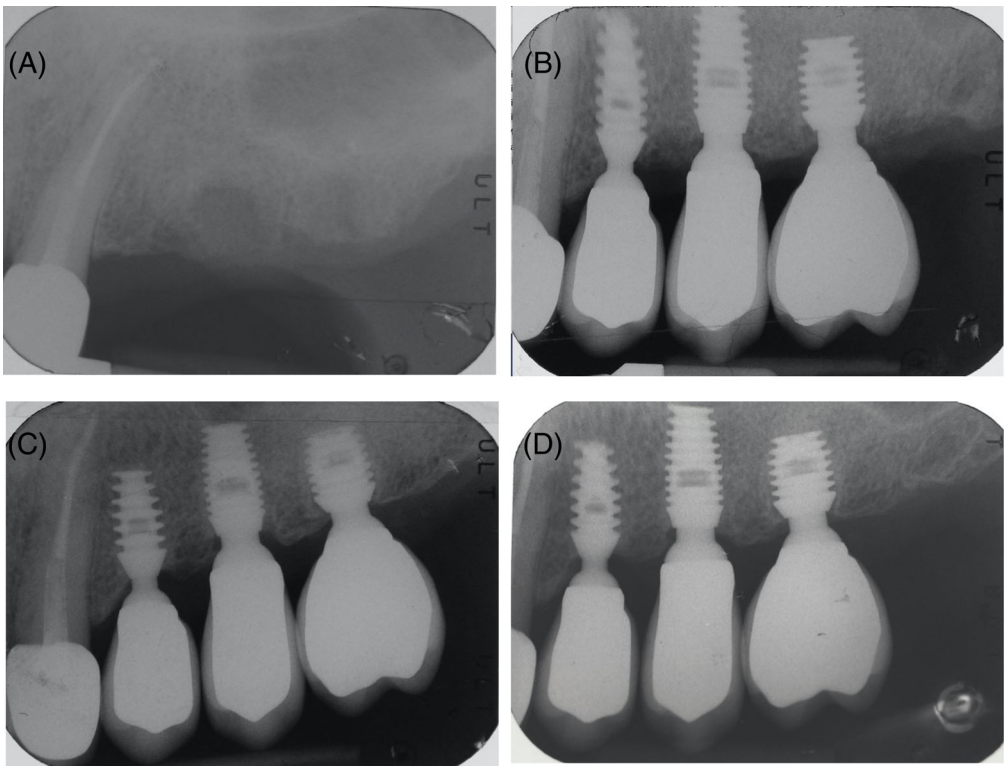

FIGURE 2 Single implants placed in 2.4, 2.5, and 2.6 sites (4 × 8 mm, 4.5 × 8 mm, and 5 × 6 mm): (A) Preoperative radiograph before implants placement; (B) radiograph obtained at time of loading; (C) radiograph obtained at 3-year follow-up; (D) radiograph obtained at 5-year follow-up

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peri-implant bone resorption greater than 1 mm during the time interval from loading to 5-year follow-up. Once the failed implants were excluded, implant success can be considered implants without signs of peri-implantitis.

For data collection, a database including all patients evaluated in the study was created with Microsoft Excel. All data analysis was carried out using Stata v.13.0 for Macintosh (StataCorp). The normality assumptions for continuous data were assessed by using the

TABLE 1 Overall implants and length-groups distribution according to study variables. Age at follow-up and oral professional hygiene/year, respectively, are presented as mean ± standard deviation and median (IQR)

Variable	Overall	5 mm	6 mm	8 mm	Test statistic	*df*	*p* Value
Sex							
Male	150 (45.05)	38 (41.76)	59 (51.30)	53 (41.73)	$\chi^2 = 2.78$	2	NS ($p = 0.24$)
Female	183 (54.95)	53 (58.24)	56 (48.70)	74 (58.27)			
Age at follow-up	59.57 ± 10.52	58.55 ± 9.82	60.34 ± 9.86	59.62 ± 11.56	$\chi^2 = 5.49$	2	NS ($p = 0.06$)
Smoking history							
No	268 (80.48)	67 (73.63)	97 (84.35)	104 (81.89)	$\chi^2 = 3.97$	2	NS ($p = 0.13$)
Yes	65 (19.52)	24 (26.37)	18 (15.65)	23 (18.11)			
ASA status							
I	159 (47.75)	47 (51.65)	53 (46.09)	59 (46.46)	$\chi^2 = 0.76$	2	NS ($p = 0.68$)
II	174 (52.25)	44 (48.35)	62 (53.91)	68 (53.54)			
Oral professional hygiene/year	3 (2)	3 (2)	3 (2)	3 (2)	$F = 0.74$	1/332	NS ($p = 0.47$)
Use of interproximal oral hygiene devices							
No	75 (22.52)	20 (21.98)	29 (25.22)	26 (20.47)	$\chi^2 = 0.80$	2	NS ($p = 0.67$)
Yes	258 (77.48)	71 (78.02)	86 (74.78)	101 (79.53)			
History of periodontal disease							
No	120 (36.04)	25 (27.47)	44 (38.26)	51 (40.16)	$\chi^2 = 4.07$	2	NS ($p = 0.13$)
Yes	213 (63.96)	66 (72.53)	71 (61.74)	76 (59.84)			
Implant tooth site							
Premolar	146 (43.84)	35 (38.46)	30 (26.09)	81 (63.78)	$\chi^2 = 36.29$	2	<0.001
Molar	187 (56.16)	56 (61.54)	85 (73.91)	46 (36.22)			
Arch							
Posterior mandible	197 (59.16)	52 (57.14)	74 (64.35)	71 (55.91)	$\chi^2 = 1.99$	2	NS ($p = 0.37$)
Posterior maxilla	136 (40.84)	39 (42.86)	41 (35.65)	56 (44.09)			
Implant diameter							
3 mm	1 (0.30)	0 (0.00)	0 (0.00)	1 (0.79)			
3.5 mm	11 (3.30)	0 (0.00)	0 (0.00)	11 (8.66)	$\chi^2 = 173.38$	6	<0.001
4 mm	81 (24.32)	43 (47.25)	1 (0.87)	37 (29.13)			
4.5 mm	112 (33.63)	0 (0.00)	55 (47.83)	57 (44.88)			
5 mm	109 (32.73)	30 (32.97)	58 (50.43)	21 (16.54)			
6 mm	18 (5.41)	17 (18.68)	1 (0.87)	0 (0.00)			
6.5 mm	1 (0.30)	1 (1.10)	0 (0.00)	0 (0.00)			
Prosthetic material							
Resin	47 (14.16)	14 (15.38)	18 (15.79)	15 (11.81)	$\chi^2 = 0.93$	2	NS ($p = 0.62$)
Porcelain	285 (85.84)	77 (84.62)	96 (84.21)	112 (88.19)			
Crown-to-implant ratio							
<2	181 (54.52)	3 (3.30)	56 (49.12)	122 (96.06)	$\chi^2 = 195.16$	2	<0.001
2–2.99	133 (40.06)	73 (80.22)	56 (49.12)	4 (3.15)			
>2.99	18 (5.42)	15 (16.48)	2 (1.75)	1 (0.79)			

Note: For all other variables, values are presented as *n* (%).

Abbreviations: ASA, American Society of Anesthesiologists; *df*, degrees of freedom; IQR, interquartile range; NS, not statistically significant.

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TABLE 2 Failures features

Site	16	24	24	26	34	35	35	44	45	46	46	47	17
Diameter	5	4	4	5	4.5	4	4.5	5	6	4	4.5	5	5
Length	6	5	8	6	8	5	6	8	5	5	8	6	6
Sex	M	F	F	F	M	F	M	M	M	F	M	F	M
Smoking history	Yes	No	No	Yes	Yes	No	No	No	No	No	No	No	No
ASA status	II	I	I	II	II	II	I	II	I	II	I	II	I
Oral professional hygiene/year	3	4	2	1	2	4	2	4	3	2	4	4	4
History of periodontal disease	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Crown-to-implant ratio	2.68	2.25	1.57	1.89	1.69	2.85	1.96	1.62	2.76	3.15	1.38	2.17	/
Failure	Late	Late	Late	Late	Late	Late	Late	Late	Late	Late	Late	Late	Early

Abbreviation: ASA, American Society of Anesthesiologists.

Shapiro–Wilk test; mean and standard deviation were reported for normally distributed data, median and interquartile range (IQR) otherwise. For categorical data, absolute frequencies, percentages and 95% confidence intervals were reported. The association between categorical variables was tested with χ^2 test; if any of the expected values was less than 5, a Fisher's exact test was performed. The comparison between the means of continuous variables in two different times was performed by using paired Student's "*t*"-test or Wilcoxon matched-pairs signed-rank test. The comparison between the means of two different groups was performed using unpaired Student's "*t*", or Wilcoxon rank-sum test. The comparison of the means among more than two groups was done using one-way analysis of variance, or Kruskal–Wallis equality-of-populations rank test. A multivariate analysis (logistic regression) was carried out to find factors associated with implant success. Significance level was set at 0.05.[22,31–33]

By way of illustration, Figures 1A–D and 2A–D report some radiographic cases.

3 | RESULTS

3.1 | Demographics

A total of 142 patients (65 men and 77 women) received at least one 8.0-, 6.0-, or 5.0-mm length single-crown dental implant. Of the patients, 78.87% (112/142) were nonsmokers, 59.15% (84/142) had an ASA status I, and 52.82% (76/142) had a history of periodontal disease. All patients were compliant with the maintenance program, receiving on average, three oral professional hygiene sessions in a year; 74.65% (106/142) of them used interproximal oral hygiene devices daily. Mean age at placement was 53.48 ± 10.39 (range 29–78) years.

Of the 333 implants placed, 127 (38.14%) were 8-mm length, 115 (34.53%) were 6-mm length, and 91 (27.33%) were 5-mm length. The majority of 8-mm length implants were placed in premolar regions, while 5- and 6-mm length implants were placed in molar regions. One implant in the posterior maxilla failed before loading, thus 332 implants in 141 patients (64 men and 77 women) were finally rehabilitated with single crowns. The mean CIR was 1.94 ± 0.85 (range 0.91–3.81) and 45.48% of the implants presented a CIR ≥2. CIR in 8-, 6-, and 5-mm length, respectively, was 1.45 ± 0.32 (range 0.91–3.06), 2.01 ± 0.48 (range 1.09–3.03), and 2.57 ± 0.59 (range 1.80–3.81), with statistically significant differences among groups ($p < 0.001$).

The implants distribution, analyzed according to length-groups, is presented in Table 1.

3.2 | Implant survival

One early failure in one patient was assessed, and 12 implants were lost and removed after functional loading in 12 different patients. The overall implant-based survival at 60-month follow-up was 96.10% (320/333). Failures features are recorded in Table 2. The overall patient-based survival was 91.55% (130/142). No association was found between survival and failure groups, and any of the covariates considered (Table 3).

3.3 | Marginal bone loss

CBL variations are reported in Tables 4 and 5. Overall average values of CBL at loading, CBL at 5-year follow-up, F-BIC at loading, F-BIC at 5-year follow-up, ΔCBL and ΔF-BIC between loading and follow-up were, respectively: 1.99 ± 1.19 mm, 1.15 ± 1.22 mm, 0.23 (0.66) mm, 0.29 (0.85) mm, 0.69 (1.27) mm, 0.01 (0.63) mm. A statistically significant difference was found for ΔCBL regarding history of periodontal disease and for ΔF-BIC regarding arch (Tables 4 and 5).

3.4 | Soft tissues conditions and implant success

Soft tissues conditions were stable at 5-year recall appointment. Average values, expressed as median (IQR), were: 3.41 (1.27) mm

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for PPD, 0.87 (0.84) for mBI, 0.54 (0.7) for mPLI, and 1.84 (1.42) mm for KT, respectively.

During the time interval from loading to follow-up, 28 implants experienced loss of supporting bone >1 mm: 19 of them (67.85%) were surgically treated with a codified protocol, which consisted in access flap surgery, concomitant chemical and mechanical decontamination (through the application of a desiccant agent and sodium bicarbonate-based abrasive air powder) of implant surface and bone grafting.[45] Out of 19 implants, peri-implantitis was thus successfully treated in 9 implants (47.36%), which demonstrated bone levels stability at the 5-year follow-up. Finally, at the 5-year follow-up, among 320 survived implants, 23 (7.19%) exhibited

TABLE 3 Analysis of overall implant survival according to included study covariates

Variable	Survival *n* (%)	Failure *n* (%)	Test statistic	*df*	*p* Value
Sex					
Male	143 (95.33)	7 (4.67)	$\chi^2 = 0.42$	1	NS ($p = 0.51$)
Female	177 (96.72)	6 (3.28)			
Smoking history					
No	258 (96.27)	10 (3.73)	$\chi^2 = 0.10$	1	NS ($p = 0.72$)
Yes	62 (95.38)	3 (4.62)			
ASA status					
I	153 (96.23)	6 (3.77)	$\chi^2 = 0.01$	1	NS ($p = 0.90$)
II	167 (95.98)	7 (4.02)			
History of periodontal disease					
No	116 (96.67)	4 (3.33)	$\chi^2 = 0.16$	1	NS ($p = 0.77$)
Yes	204 (95.77)	9 (4.23)			
Implant tooth site					
Premolar	139 (95.21)	7 (4.79)	$\chi^2 = 0.54$	1	NS ($p = 0.45$)
Molar	181 (96.79)	6 (3.21)			
Arch					
Posterior mandible	189 (95.94)	8 (4.06)	$\chi^2 = 0.03$	1	NS ($p = 0.55$)
Posterior maxilla	131 (96.32)	5 (3.68)			
Implant diameter					
3 mm	1 (100.00)	0 (0.00)			
3.5 mm	11 (100.00)	0 (0.00)			
4 mm	77 (95.06)	4 (4.94)	$\chi^2 = 1.47$	6	NS ($p = 0.81$)
4.5 mm	109 (97.32)	3 (2.68)			
5 mm	104 (95.41)	5 (4.59)			
6 mm	17 (94.44)	1 (5.56)			
6.5 mm	1 (100.00)	0 (0.00)			
Implant length					
5 mm	87 (95.60)	4 (4.40)	$\chi^2 = 0.31$	2	NS ($p = 0.82$)
6 mm	110 (95.65)	5 (4.35)			
8 mm	123 (96.85)	4 (3.15)			
Prosthetic material					
Resin	45 (95.74)	2 (4.26)	$\chi^2 = 0.06$	1	NS ($p = 0.68$)
Porcelain	275 (96.49)	10 (3.51)			
Crown-to-implant ratio					
<2	175 (96.69)	6 (3.31)	$\chi^2 = 0.24$	2	NS ($p = 0.68$)
2–2.99	128 (96.24)	5 (3.76)			
>2.99	17 (94.44)	1 (5.56)			

Note: For all variables, values are presented as *n* (%).
Abbreviations: ASA, American Society of Anesthesiologists; *df*, degrees of freedom; NS, not statistically significant.

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TABLE 4 Overall CBL [mm] distributions and analysis of ΔCBL [mm] according to history of periodontal disease, implant tooth type, arch, implant length, prosthetic material, and CIR

	CBL						
	Loading time	Follow-up time	ΔCBL				
Variable	Mean ± *SD*	Mean ± *SD*	Median	IQR	Test statistic	*df*	*p* Value
History of periodontal disease							
No	2.26 ± 1.10	1.54 ± 1.14	0.61	0.87	$Z = -2.03$		0.04
Yes	1.85 ± 1.22	0.93 ± 1.21	0.74	1.54			
Implant tooth type							
Premolar	1.95 ± 1.30	1.10 ± 1.37	0.72	1.41	$Z = 0.77$		NS ($p = 0.43$)
Molar	2.03 ± 1.10	1.18 ± 1.10	0.67	1.22			
Arch							
Posterior mandible	1.93 ± 1.28	1.06 ± 1.29	0.72	1.48	$Z = 0.64$		NS ($p = 0.51$)
Posterior maxilla	2.08 ± 1.05	1.27 ± 1.11	0.67	0.89			
Implant length							
5 mm	1.96 ± 1.15	1.14 ± 1.21	0.64	1.54	$\chi^2 = 0.45$		NS ($p = 0.79$)
6 mm	2.11 ± 1.17	1.28 ± 1.10	0.68	1.23		2	
8 mm	1.92 ± 1.24	1.04 ± 1.33	0.74	1.26			
Prosthetic material							
Resin	1.86 ± 1.19	0.96 ± 1.20	0.74	1.20	$Z = 0.27$		NS ($p = 0.78$)
Porcelain	2.02 ± 1.19	1.18 ± 1.23	0.69	1.28			
Crown-to-implant ratio							
>2	1.88 ± 1.18	1.04 ± 1.26	0.72	1.23	$\chi^2 = 1.33$		NS ($p = 0.51$)
2–2.99	2.00 ± 1.12	1.18 ± 1.08	0.65	1.32		2	
>2	3.10 ± 1.29	1.99 ± 1.47	0.87	1.34			

Note: CBL and its variations are presented as mean (*SD*) or median [IQR].
Abbreviations: CBL, crestal bone level; CIR, crown-to-implant ratio; *df*, degrees of freedom; IQR, interquartile range; NS, not statistically significant.

peri-implant mucositis and 19 (5.94%) presented peri-implantitis, for a total of 42 implants (13.13%) presenting biological complications. The overall implant-based success at 60-month follow-up was 94.06% (301/320). The overall patient-based success was 90% (117/130). Significant differences ($p < 0.05$) were found between groups regarding sex, ASA status, and implant diameter (Table 6).

The logistic regression model (Table 7) considered sex, ASA status, diameter, and history of periodontal disease ($p < 0.10$) for the multivariate analysis: being male, ASA status I, and having history of periodontal disease finally showed to have an independent effect on the probability of implant success.

4 | DISCUSSION

In this study, concerning implant survival outcomes and marginal bone levels changes over time, no statistical differences among 8-, 6-(short), and 5-mm length (ultra-short) implants, supporting single crowns in the posterior maxilla and mandible, were demonstrated 5 years after loading. In the past decades, several authors supported the idea that <8 mm in length implants could be considered a valid option of treatment not only in case of splinted reconstructions but also for single-unit restorations.[30,46–48] However, considering that most of the studies were conducted with a short (1–3 years) follow-ups, other authors[4] recommended that these results should be interpreted with caution. It was postulated that, in case of ultra-short single-crown implants, the long-term influence of higher CIRs, and increased crown heights on marginal bone loss should be carefully evaluated before endorsing the use of 6-mm length implants with single crowns in daily clinical practice.

The most recent studies with longer follow-ups seem to confirm the hypothesis that ultra-short implants supporting single crowns present higher variability, lower predictability, and poorer survival rates compared to longer implants.[23,29,49] On the basis of several systematic reviews with at least 5 years of follow-up,[6,15,19,50] it has been proposed that ultra-short implants, mainly suggested in cases of low vertical bone height and when complementary surgical procedures are not favorable, should be splinted. Specific factors, mostly related to the relationship between CIR and marginal bone loss, might have played a role in declaring these indications. Even if many studies and systematic reviews[4,23,49] did not observe a negative influence of disproportionate CIR on CBL stability, an increased unfavorable CIR, according to traditional standards, is typical of rehabilitations using

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short and ultra-short implants, and seems to exert a worsening of performances of these implants when supporting single crowns.[41]

Even if nonsplinted crowns allow easier hygiene procedures, have a passively fitting framework, and typically have better esthetics, splinting implant crowns leads to less stress transmitted to each bone-implant interface.[51,52] Finite element analysis[53,54] showed that the higher the CIR, the higher the tension in the bone profile adjacent to the most cervical part of the implants. In presence of high lateral masticatory forces[52] a single crown may act as a lever transferring stress along the cortical bone surrounding the implant.[55] This may result in gradual crestal bone loss, which, in the in case of ultra-short implants, may culminate in premature bone loss.

Malchiodi et al.,[39] in a 3-year prospective study on splinted and single ultra-short implants, concluded that, above certain limits, there is a statistical correlation between CIR and crestal bone loss. This suggests the existence of specific threshold values for CIR to avoid excessive tension at the abutment-bone interface. Rossi et al.,[49] in a prospective study on thirty 10-mm length and thirty 6-mm length implants, found a survival rate of 96.7% and 86.7% after 5 years, with an anatomical CIR of 1.4 and 1.75. Naenni et al.,[29] after 5 years of follow-up, reported for forty-seven 6.0-mm length and forty-seven 10-mm length implants, showed a median CIR of 1.75 and 1.4, and an implant survival of 86.7% and 100%, respectively. Villarinho et al.,[23] in a prospective study with a 5-year follow-up, found a survival rate of only 91.3% for 46 single crowns in 6-mm length implants with a CIR of 1.66. In the present study, after 5 years of loading, a hundred and ten 6-mm length, and eighty-seven 5-mm length locking-taper implants, with an average CIR of 2.01 and 2.57, had a cumulative survival rate of 95.65%, and 95.6%, respectively. In particular, the majority of 5-mm length implants had a CIR >2 (80.22%), while the 16.48% had a CIR even >3. Nevertheless, after 5 years, no statistically significant differences were recorded for average marginal bone levels changes among 5 mm ultra-short and 6 mm, and 8 mm short implants; those values were 0.64 mm, 0.68 and 0.74 mm, respectively.

As implied in the discussion of the literature above, previous studies, particularly regarding disproportionate CIR in 5-mm length implants[39,56–59] do not allow for definitive conclusions. In part this is due to the mixing of splinted and nonsplinted restorations as well as abbreviated follow-up periods. Whereas in the present study the macrodesign of the implant system, presenting plateaus and healing chambers, have shown to increase the implant surface area (mm^2) in bone, when compared to implants of similar dimensions but with

TABLE 5 Overall F-BIC [mm] distributions and analysis of ΔF-BIC [mm] according to history of periodontal disease, implant tooth type, arch, implant length, prosthetic material, and CIR

	F-BIC						
	Loading time	Follow-up time	ΔF-BIC				
Variable	median (IQR)	median (IQR)	Median	IQR	Test statistic	*df*	*p* Value
History of periodontal disease							
No	0.14 (0.56)	0.07 (0.70)	0.01	0.43	$Z = -1.70$		NS ($p = 0.08$)
Yes	0.25 (0.70)	0.42 (0.89)	0.09	0.79			
Implant tooth type							
Premolar	0.25 (0.70)	0.41 (0.95)	0.07	0.73	$Z = 1.29$		NS ($p = 0.19$)
Molar	0.21 (0.61)	0.27 (0.74)	0.01	0.50			
Arch							
Posterior mandible	0.28 (0.72)	0.27 (0.81)	0.01	0.59	$Z = -2.03$		0.04
Posterior maxilla	0.21 (0.50)	0.37 (0.92)	0.08	0.78			
Implant length							
5 mm	0.21 (0.58)	0.32 (0.87)	0.01	0.59	$\chi^2 = 3.28$		NS ($p = 0.19$)
6 mm	0.27 (0.61)	0.24 (0.75)	0.01	0.48		2	
8 mm	0.23 (0.73)	0.40 (0.88)	0.05	0.73			
Prosthetic material							
Resin	0.33 (0.58)	0.41 (0.95)	0.23	0.78	$Z = 0.91$		NS ($p = 0.36$)
Porcelain	0.21 (0.68)	0.29 (0.83)	0.01	0.58			
Crown-to-implant ratio							
>2	0.32 (0.72)	0.31 (0.88)	0.01	0.82	$\chi^2 = 3.10$		NS ($p = 0.21$)
2–2.99	0.13 (0.53)	0.30 (0.78)	0.01	0.44			
>2	0.19 (0.53)	0.01 (0.80)	0.01	0.38			

Note: F-BIC and its variations are presented as mean (*SD*) or median [IQR].
Abbreviations: CIR, crown-to-implant ratio; *df*, degrees of freedom; F-BIC, first bone-to-implant contact; IQR, interquartile range; NS, not statistically significant.

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TABLE 6 Analysis of overall implant success according to included study covariates

Variable	Success *n* (%)	No success *n* (%)	Test statistic	*df*	*p* Value
Sex					
Male	130 (90.91)	13 (9.09)	$\chi^2 = 4.60$	1	0.03
Female	171 (96.61)	6 (3.39)			
Smoking history					
No	241 (93.41)	17 (6.59)	$\chi^2 = 1.01$	1	NS ($p = 0.54$)
Yes	60 (96.77)	2 (3.23)			
ASA status					
I	139 (90.85)	14 (9.15)	$\chi^2 = 5.41$	1	0.03
II	162 (97.01)	5 (2.99)			
History of periodontal disease					
No	113 (97.41)	3 (2.59)	$\chi^2 = 3.65$	1	NS ($p = 0.08$)
Yes	188 (92.16)	16 (7.84)			
Implant tooth site					
Premolar	130 (93.53)	9 (6.47)	$\chi^2 = 0.12$	1	NS ($p = 0.72$)
Molar	171 (94.48)	10 (5.52)			
Arch					
Posterior mandible	180 (95.24)	9 (4.76)	$\chi^2 = 1.14$	1	NS ($p = 0.28$)
Posterior maxilla	121 (92.37)	10 (7.63)			
Implant diameter					
3 mm	1 (100.00)	0 (0.00)			
3.5 mm	9 (81.82)	2 (18.18)			
4 mm	76 (98.70)	1 (1.30)	$\chi^2 = 23.47$	6	0.01
4.5 mm	101 (92.66)	8 (7.34)			
5 mm	99 (95.19)	5 (4.81)			
6 mm	15 (88.24)	2 (11.76)			
6.5 mm	0 (0.00)	1 (100.00)			
Implant length					
5 mm	81 (93.10)	6 (6.90)	$\chi^2 = 1.26$	2	NS ($p = 0.55$)
6 mm	102 (92.73)	8 (7.27)			
8 mm	118 (95.93)	5 (4.07)			
Prosthetic material					
Resin	44 (97.78)	1 (2.22)	$\chi^2 = 1.29$	1	NS ($p = 0.49$)
Porcelain	257 (93.45)	18 (6.55)			
Crown-to-implant ratio					
<2	165 (94.29)	10 (5.71)	$\chi^2 = 0.03$	2	NS ($p = 0.98$)
2–2.99	120 (93.75)	8 (6.25)			
>2.99	16 (94.12)	1 (5.88)			

Note: For all variables, values are presented as *n* (%).
Abbreviations: ASA, American Society of Anesthesiologists; *df*, degrees of freedom; NS, not statistically significant;.

screw root form macrodesign, eventually corroborating the use of 5-mm length ultra-short implants supporting single crowns within the range of CIR investigated herein.[60] In addition, such macrodesign presents a double platform switch that was shown to be advantageous since it seems to load bone coronal to the implant-abutment interface (IAI) through the base of the abutment. In this platform design, an implant shoulder gradually slopes inward and coronally, toward the IAI, creating space for crestal bone, while the base of the implant abutment presents as a loading surface through which compressive loads are exerted on existing or potential crestal bone.[61] This specific feature can provide favorable considerations for single crown restorations, overcoming the previously described limits in terms of stress

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TABLE 7 Analysis of overall implant success according to included study covariates

Variable	Odds ratio	$p > \|z\|$	[95% CI]
Sex	2.91	0.04	[1.02, 8.26]
ASA status	4.07	0.01	[1.39, 11.95]
History of periodontal disease	0.24	0.03	[0.06, 0.90]
Implant diameter	0.69	0.37	[0.30, 1.54]

Note: For all variables, values are presented as *n* (%).
Abbreviations: ASA, American Society of Anesthesiologists; CI, confidence interval; *df*, degrees of freedom; NS, not statistically significant.

distribution in case of high CIR: vertical, horizontal, and rotational forces are adequately transmitted, providing stable functioning over time.[33]

Furthermore, this hypothesis is supported as follows from the data presented in literature from other studies on the same type of implant. Schulte et al.,[62] after an average time of 2.3 years of follow-up (0.1–7.4 years), recorded a survival rate of 98.2% for 889 single-tooth locking-taper implants; CIR values for short or ultra-short implants ranged from 0.5:1 to 3:1; the average CIR for implants in function was 1.3; the average CIR for failed implants was 1.4; authors concluded that there was no clinically significant difference between groups regarding CIR. Urdaneta et al.,[40] evaluating the effect of increased CIR on 326 short and ultrashort locking-taper implants presenting a mean CIR of 1.6 (range 0.79–4.95), reported an implant survival of 98% after 6 years. Two retrospective studies[22,31] with 3 years of follow-up, reported a survival rate of 95.12% and of 95.83%, respectively, for forty-one and forty-eight 5-mm implants supporting single crown in the maxilla and in the mandible.

The promising 5-year outcomes reported in this study for implant survival and bone levels stability—even in presence of unfavorable high CIR, may be explained also by a series of human retrieval published studies of implants with the same macrodesign, consistently showing that from initial woven bone formation at the healing chambers, further bone morphologic evolution occurs toward a Haversian-like configuration that over time increases significantly in mechanical properties.[63–65] The presence of a screwless, locking-taper implant-abutment connection confers greater mechanical stability to the implant/crown assembly, previously shown to provide an impervious seal to microbial penetration or infiltration,[66] an absence of micro-movements, or micro gaps at the IAI, which lead to minimal bone resorption.[22,31–33] In this way, adjacent bone is hardly loaded at levels that could exceed the minimum effective strain necessary for bone modeling and remodeling. A study by Chou et al.[67] reported bone density distributions similar to that of the natural tooth, which led the authors to conclude that plateau-design implants are more suitable in preventing bone loss.

Differently from the initially mentioned studies supporting the use of splinted crowns with disproportionate CIR of short and ultra-short implants, single restorations with distinctive features, such as plateau design, locking-taper connection and sloping shoulder, could thus be advisable, demonstrating to preserve crestal bone.

In the present study, the analysis of overall implant success, including study covariates, showed that implant diameter may influence the success, but it has little effect on the survival of ultra-short implants. These results are in agreement with a recent study,[68] where ultra-short implants of different diameter did not result in significant differences in the analysis of failure from a mechanical perspective. In this study, even if different for the implant system analyzed, four implants were lost in the maxilla, and nine in the mandible, showing no statistical differences between groups. Other studies have reported no difference in failure rates regarding the arch,[69] while other authors[4] reported a higher failure rate for single crowns supported by short implants in the mandible. In contrast, other reviews[70,71] showed a higher incidence of loss in the maxilla.

It is well-known in literature that standard implants survival rates may not differ between periodontal and nonperiodontal patients, while patients with a history of periodontitis may instead experience a greater number of biological complications and have a lower success rate compared to periodontally healthy patients.[33] The results of the present study seem to corroborate this finding, as no statistically different implant survival (96.67% and 95.77%) was, respectively, found between healthy patients and patients with history of periodontitis. Nevertheless, in the subgroup of participants that presented a history of chronic periodontitis (52.82%), even while undergoing intensive supportive periodontal therapy, peri-implantitis occurred/progressed at higher rate than in periodontally healthy patients. This subgroup also had an inferior, although not significant, success rate (92.16%), compared to nonperiodontal patients (97.41%). At the moment, only few studies[26,33,72–74] are present in literature regarding the impact of periodontal disease on short implants survival, and even these few reported short-term contradictory results, therefore, it is not possible to draw a definitive conclusion. At this point in time, this topic should require further analysis to clarify the influence of periodontitis on the long-term success rate of ultra-short implants supporting single crowns.

Regarding possible implications between periodontal conditions and other factors, it was reported that reinforced composite resin material appears to accumulate more plaque deposits than titanium resulting in at least surface mucosal inflammation of peri-implant tissues.[75] On the other hand, other authors[76–79] have also reported that they found no significant differences in terms of implant survival and marginal bone loss between resin and porcelain restorations. In this

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study, there were no statistical differences between the two prosthetic materials in terms of implant survival and CBLs (CBL and F-BIC). In addition to that, variables related to oral hygiene habits and professional maintenance should be considered, especially for patients with history of aggressive periodontal disease, whose compliance to strict supportive protocols[33] is fundamental for the maintenance of a sufficient level of peri-implant health.

Comparing the results of this study with the previous similar studies on locking-taper implants done at 3-year follow-up, some issues remain critical. Main limitations related to its retrospective nature, even if reduced, still consist in a nonbalanced distribution among implant length-groups and arch-groups, besides the University setting (single-centre). However, a proper evaluation of clinical and radiographic conditions at a longer-term follow-up (5 years), as well as limiting the present analysis to single crown restorations, suggests predictability of treatments using short and ultrashort locking-taper implants even in presence of highly disproportionate CIR.

5 | CONCLUSIONS

Outcomes show stable CBLs over time, with no statistically significant differences between survival and success with short (8- and 6-mm length), and ultra-short (5-mm length) implants. Five-year outcomes report single-crown restorations as a successful option in the rehabilitation of atrophic posterior jaws. Further investigations with longer follow-up and prospective design, and with a comparison between single and splinted crowns, are necessary to validate these conclusions.

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CONFLICT OF INTEREST

The authors declare no conflicts of interests.

AUTHOR CONTRIBUTIONS

Giorgio Lombardo: Concept and design, data interpretation, critical revision, and approval of article. **Annarita Signoriello**: Data collection and analysis, planning of statistics, drafting article. **Mauro Marincola**: Concept and design, data interpretation, critical revision, and approval of article. **Pietro Liboni**: Data collection and analysis, drafting article. **Estevam A. Bonfante**: Data interpretation, critical revision, and approval of article. **Pier F. Nocini**: Data interpretation, critical revision, and approval of article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Annarita Signoriello https://orcid.org/0000-0002-9761-4046

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APPENDIX A.

Exclusion criteria for the study were[22,31–33]: presence of active infection at an implant site; ASA status III, IV,V, and VI (according to the American Society of Anesthesiologists' classification), that is, severe systemic diseases or substantive functional limitations which contraindicated implant surgery (such as drug or alcohol abuse, uncontrolled diabetes mellitus, immunosuppression or immunodepression, severe autoimmune diseases, treatment or past treatment with intravenous amino-bisphosphonates for metastatic bone diseases, radiotherapy to head or neck within 2 years prior to treatment, history of malignancy or chemotherapy within the previous year, treatment with oral amino-bisphosphonates for >3 years, morbid obesity, active hepatitis, severe renal disease, severe cardiovascular conditions, recent history of myocardial infarction or transient ischemic attack); untreated periodontitis; poor oral hygiene and motivation; current pregnancy or lactation; heavy smoking (>25 cigarettes per day); severe clenching or bruxism.

A complete clinical and radiographic evaluation (dental and periodontal status; panoramic and periapical radiograph, cone beam computed tomography) and basic periodontal treatment was performed before implant placement. A preoperative medication consisting of 2 g of Augmentin (875 mg amoxicillin + 125 mg clavulanic acid), or 1 g of Klacid (clarithromycin 500 mg) if allergic to penicillin, was given 1 h before surgery. All surgical procedures were performed under local anesthesia, using only articaine 4% with adrenaline 1:100 000 (Citocartin) or articaine 4% with adrenaline 1:100 000 (Citocartin) associated with oral sedation (Halcion 0.25 mg).[22,31–33]

A full-thickness flap was performed, and a high-speed 2.0-mm diameter pilot drill (with a cutting edge at the apical portion and drilling at 1100 rpm) with external saline irrigation was used to perforate the cortical plate. Final pilot drilling length was determined by measuring residual bone height and adding at least 1.0 mm to the selected implant length to allow for a subcrestal implant placement. Latch reamers presenting a 0.5 mm progressive increase in diameter were used at 50 rpm, without external irrigation to widen the osteotomy until the final implant diameter was reached. The selected implant was manually inserted into the osteotomy, a healing plug was placed in the implant well, and autogenous bone collected during the slow speed preparation of the osteotomy was used to fill the gap between the implant and the bony walls. The incisions were closed by single polyglycolic acid sutures (Vycril; ACE Surgical Supply Co.). A postoperative periapical radiograph was taken, postoperative instructions were given as well as antibiotic and analgesic prescriptions.[22,31–33]

The IAC is a cementless restoration for single-tooth implants, where the crown is extraorally chemomechanically bonded to the coronal part of a titanium alloy nonshouldered or shouldered locking-taper abutment, reduced using carbide burs to provide for smooth surface contours and subgingival margins: in this way, the implant abutment and the crown material constitute one unit.[34] The crown is inserted into place by mean a gentle tapping using a 250-g mallet, by mean a crown seating tip supplied by the manufacturer and a custom-made acrylic tapping jig to ensure accurate proper seating.

When composite material was preferred for the crown, a microhybrid composite containing 73% by weight microfine ceramic particles, embedded in an organic polymer matrix (Ceramage; Shofu Inc.), was used. In case of choice of ceramic material, a bilayer crown was planned using a zirconia framework veneered with feldspar ceramic (Ceramica Natural ZiR; Tressis Italia srl).

Patients with a history of treated periodontitis were characterized by previously assessed chronic forms of periodontal disease, corresponding to stage I, II or III, and grade A or B, according to the latest updates on classification of periodontal and peri-implant diseases.[35] These patients were subjects following a regular maintenance program on a reduced periodontium every 3 months to ensure gingival health at the time of implant placement. On the other hand, periodontally healthy patients were subjects never affected by any form of periodontal disease.[33]

Peri-implant bone levels were measured through digitally scanned intraoral radiographs, performed with a paralleling technique, using Rinn centering devices (Rinn XCP Posterior Aiming Ring-Yellow; Dentsply). This was done immediately after implant placement, at healing abutment placement, at prosthetic loading, and after 5 years of loading. Measurements were taken as previously described.[22,31–33] The IAI was taken as a reference for measurements (Figure A1). CBL was measured on mesial and distal sides as the linear distance between the IAI and the highest point of the interproximal bone crest parallel to the lateral sides of the implant body: a positive value was given when the crest was located coronally to the IAI and a negative value when the crest was located apically to the IAI; for every implant, at each examination interval, an average mesial-distal value was calculated. F-BIC was defined as the first most coronal bone-to-implant relationship visible at the first line of contact, on both mesial and distal sides; if F-BIC matches with IAI, the measurement was 0; if it is located apically, the measurement was a positive value.[22,31–33] As described in the literature, implants were divided into two groups on

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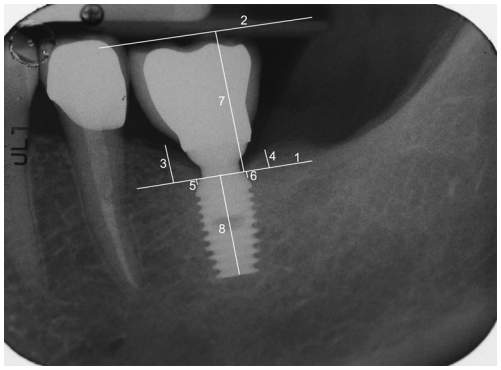

FIGURE A1 Schematic example of the references for peri-implant bone levels measurements. (1) Implant-abutment interface; (2) most occlusal point line; (3) crestal bone level (CBL) on the mesial side; (4) CBL on the distal side; (5) first bone-to-implant contact (F-BIC) on the mesial side; (6) F-BIC on the distal side; (7) crown length; (8) implant length

the basis of presenting a CIR less than or greater than 2. The crown height was measured on the radiograph immediately after the prosthetic loading, from the most occlusal point to the IAI. Anatomical CIR (in which the fulcrum is positioned at the interface between the implant shoulder and the crown-abutment complex) was calculated by dividing the digital length of the crown by the digital length of the implant.[22,31–33]

Measurements were assessed with the aid of a software program (Rasband, W.S., ImageJ, U. S. National Institutes of Health) which uses a measuring tool in conjunction with a magnification tool. To correct the distortion of the radiographic image, the apparent size of each implant (measured directly on the radiograph) was compared with the actual length to determine, with adequate precision, the amount of any changes of the crestal bone around each implant. The measurements were made to the nearest 0.01 mm. One dentist who was not involved in the treatment of the patients completed all the measurements on periapical radiographs; the observation intervals of radiographs were masked to the examiner. Before the start of the study, this investigator was calibrated for adequate intraexaminer levels of accuracy and reproducibility in recording the radiographic parameters. Three radiographs were utilized for this purpose: duplicate measurements for CBL, F-BIC, and CIR were collected with an interval of 24 h between the first and second recording. The intraclass correlation coefficients, used as a measure of intraexaminer reproducibility, had to be greater than 0.8.[22,31–33]

The study presents compliance with the STROBE checklist guidelines.[80]

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