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A prospective, multicentre study of 6-mm short implants in posterior alveolar bone supporting splinted crowns: A 5-year follow-up study

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Abstract

Aim: To evaluate the clinical and radiographic outcomes of 6-mm short implants, placed in the posterior jaws and supporting splinted crowns, at 5 years after early loading.

Materials and Methods: Forty-five patients with 95 implants (diameter: 4 mm; length: 6 mm) were enrolled at three centres. Two to three implants were placed in either the maxillary or the mandibular posterior region in each patient and restored with screw-retained splinted crowns at 6 weeks later. Clinical and radiographic outcomes were evaluated at implant placement, at loading, and at 6, 12, 24, 36, and 60 months after loading. Biological and mechanical complications were recorded. Marginal changes in bone level in relation to clinical parameters were evaluated using a generalized linear mixed model.

Results: During the 5 years of follow-up, the mean change in the marginal bone level (MBL) was 0.04 ± 0.14 mm. Four implants in four patients were lost before loading, one implant in one patient was lost at the 5-year follow-up, and two patients were lost to follow-up. The survival and success rates were 88.4% (38/43) at the patient level. The incidence rates of peri-implant mucositis and peri-implantitis were 29.4% and 7.0%, respectively. The rate of technical complications was 14.0%.

Conclusions: Over a 5-year period, 6-mm short implants supporting early loaded splinted crowns in maxillary or mandibular posterior regions showed stable MBLs and acceptable technical and biological complication rates.

KEYWORDS
early loading, marginal bone loss, posterior jaws, short implant, survival rate

Clinical Relevance

Scientific rationale for study: Short implants are an alternative to standard long implants combined with bone grafting and have been used in patients with limited vertical bone in the posterior region. However, there is a lack of long-term studies on the clinical performance of short (6 mm) implants used in the posterior region.

Principal findings: Short implants of 6 mm resulted in survival and success rates of 88.4%, with an acceptable complication rate and stable marginal bone level changes after 5 years.

Practical implications: Short implants of 6 mm supporting splinted crowns can be used in the maxillary or mandibular posterior region. Regular periodontal maintenance, however, is an important determinant of the long-term success of short dental implants.

1 | INTRODUCTION

Implant therapy has become widely accepted as a method of oral rehabilitation in both partially and completely edentulous patients. Severe periodontitis, pneumatization of the maxillary sinus, anatomic restrictions, and post-extraction alveolar ridge resorption can lead to insufficient vertical bone height. This presents a challenge for conventional dental implants in the posterior region of the upper and lower jaws (Garbacea et al., 2012; Calin et al., 2014). Dental implant surgery in patients with a compromised crestal bone height requires supplementary surgical procedures, such as maxillary sinus floor elevation, guided bone regeneration, block grafting, and inferior alveolar nerve transposition (Felice et al., 2014; Schwartz, 2020). Short implants, as an alternative, have the advantages of reduced morbidity, treatment time, and cost (Renouard & Nisand, 2006; Esposito et al., 2011; Thoma et al., 2015; Pieri et al., 2017) compared to conventional implants in combination with complex surgical procedures.

Studies on short implants have reported conflicting results. Most earlier studies used implants with machined surfaces and reported low survival rates (Hagi et al., 2004; Perelli et al., 2011). However, recent improvements in implant design and surface properties have yielded outcomes comparable to those of longer implants (Pieri et al., 2012; Bechara et al., 2017; Pohl et al., 2017). A few studies have demonstrated that splinted adjacent short implants in the posterior jaws perform better, particularly for implants with higher crown-to-implant ratios (Misch et al., 2005; Hauchard et al., 2011).

In previous clinical studies, short-implant (≤6 mm) survival rates were similar to those of standard implants (>6 mm) (Pieri et al., 2017; Abduljabbar et al., 2018; Thoma et al., 2018; Guljé et al., 2019a, 2019b). However, one study found that over 5 years, the survival rate of 6-mm implants was significantly lower than that of 10-mm implants (86.7% vs. 96.7%) (Rossi et al., 2016). Delayed implant failures after a loading period of more than 5 years have also been reported, mainly due to peri-implantitis (Dreyer et al., 2018). Therefore, long-term prospective studies (≥5 years) are needed to evaluate the biological and technical outcomes of short (6-mm) implants.

The primary aim of this study was to evaluate changes in marginal bone level (MBL) during a 5-year follow-up after loading. The secondary objectives included evaluation of the clinical parameters, biological and mechanical complications, and implant survival and success rates.

2 | MATERIALS AND METHODS

2.1 | Study design

This study was a prospective, multicentre clinical study performed at three centres in China: the Department of Periodontology, Peking University School of Stomatology (Centre 1); the Second Dental Center, Peking University School of Stomatology (Centre 2); and the Department of Oral and Maxillofacial Surgery, the First Dental Center, Peking University School of Stomatology (Centre 3). The study was approved by the Ethics Committee of Peking University Medical Center and followed the guidelines proposed in the STROBE statement for reporting observational studies (von Elm et al., 2008). All surgeries and clinical observations were performed by a maximum of three experienced dentists in each of the centres. Before commencing the study, a meeting was held to develop inspection standards, and relevant training was provided to all investigators to ensure intra- and inter-examiner repeatability. Study participants were recruited between February 2011 and February 2012. All participants signed an informed consent prior to the start of the study.

2.2 | Sample size calculation

The required sample size was estimated based on the 5-year MBL data reported in a previous study (Wennstrom et al., 2004), using the PASS 11 software (NCSS, LLC., Kaysville, UT, USA). The power was set at 90%, alpha at .05, mean deviation at .76, minimum detectable difference between visits at 0.5 mm, and correlation between measures within an individual at .65. Measurement repetitions were 7, covariance type was AR(1), and the minimal sample size was 23 patients. To ensure the accuracy of the study variables and to compensate for possible losses to follow-up, we decided on a sample size of 45 patients.

2.3 | Study sample

The inclusion criteria were as follows: signed informed consent; age 20–75 years at enrollment; no systemic diseases; partial edentulism in the posterior maxilla or mandible (of at least 4 months duration); need for 2–3 adjacent implants (premolars or molars); presence of natural teeth adjacent to the planned implant sites; available bone height >6 mm and ridge width ≥6 mm at the implant sites as assessed via cone beam computed tomography; and opposing natural teeth, partial prosthesis, or implants.

Individuals were excluded from this study if their medical history included bone grafting at the planned implant sites, radiation to the head or neck region, or chemotherapy within the previous 5 years. Uncontrolled diabetes mellitus, untreated periodontitis, smoking more than 10 cigarettes per day, drug abuse, and inability to comply with the study were also exclusion criteria.

2.4 | Clinical procedures

A full-mouth periodontal evaluation was performed in accordance with the current international classification scheme of periodontal diseases (Caton et al., 2018; Murakami et al., 2018; Papapanou et al., 2018). Periodontal therapy was performed in all patients to ensure no sites with a probing depth (PD) greater than 5 mm at the time of implant placement (IP).

2.4.1 | Implant placement

The implant surgery was performed following the standard one-stage protocol, according to the manufacturer's instructions. The patients rinsed with 0.2% chlorhexidine solution for 1 min pre-operatively. The surgery was performed under local anaesthesia. After flap elevation, two or three cylindrical titanium dental implants (OsseoSpeed TX, Dentsply Sirona, York, PA, USA), 6 mm in length and 4 mm in diameter, were placed. Bone quality was determined simultaneously (Lekholm & Zarb, 1985). Primary implant stability was measured via insertion torque and subsequently manually. In accordance with the protocol, implants with healing abutment were allowed 6 weeks for transmucosal healing. In cases of primary stability less than 15 Ncm, the implants were left submerged. A periapical radiograph was taken post-operatively. Patients were instructed to rinse with 0.12% chlorhexidine solution twice a day for 2 weeks. Amoxicillin (erythromycin in cases of penicillin allergy), for 1 week, and analgesics, if required, were prescribed post-operatively. To avoid excessive loading during the initial healing period, patients were advised to take soft foods before provisional prosthetic restoration. Sutures were removed after 7 days.

2.4.2 | Prosthetic procedure

At 5 weeks after IP, implant stability was measured manually. Uni-abutments were connected and tightened to 15 Ncm. Abutment-level impressions were recorded, and provisional screw-retained splinted polymer porcelain crowns were fabricated and delivered in full functional occlusion at 6 weeks after IP. A final screw-retained fixed splinted prosthesis (metal–ceramic) was installed on the uni-abutment and torqued to 15 Ncm at 6 months after the provisional prothesis.

2.5 | Follow-up

Follow-ups were performed at 6 weeks after IP and at 6, 12, 24, 36, and 60 months after temporary loading (T0). Clinical and radiographic parameters were recorded. At each visit, oral hygiene procedures were re-emphasized, and supragingival scaling was performed for both natural teeth and implants. Subgingival scaling was also performed if necessary. Supportive care for implants was based on the cumulative interceptive supportive therapy (CIST) programme (Lang et al., 2000; Smeets et al., 2014).

2.6 | Primary outcome measure

The primary outcome measure was the change in peri-implant MBL between loading/IP and each follow-up visit. At IP, at temporary prosthesis placement (loading, baseline), and at 6, 12, 24, 36, and 60 months after loading, periapical radiographs were obtained using the standard parallel technique fixed by stents (Figure 1). Two independent examiners performed the measurements using an image analysing tool (The Geometer's Sketchpad, version 5.01, Key Curriculum Press, USA). The radiographs were individually calibrated on the basis of implant length, and the distance was recorded to the nearest 0.1 mm. MBL was determined as the distance between a reference point on the implant (i.e., the junction of the machined bevel and the start of the micro-thread) and the most coronal bone-to-implant contact point on the mesial and distal aspects of the implant. If the reference point was below the coronal bone-to-implant contact, the value was considered negative. The mean of the mesial and distal aspects of an implant was recorded as the MBL. Changes in the MBL were calculated from IP to T0 and from T0 to each follow-up visit.

2.7 | Secondary outcomes

2.7.1 | Clinical parameters

The following parameters were evaluated: presence of plaque, as detected by running a probe across the marginal surface of the abutment or the crown; PD, measured as the distance between the mucosal margin and the bottom of the pocket (in millimetres); and bleeding on probing (BOP), as detected by probing to the bottom of the pocket.

The first 3 years of follow-up were performed by each centre independently. The clinical parameters mentioned above were recorded at four sites—mesial, distal, buccal, and lingual/palatal—for each implant (Han et al., 2018). The 5-year follow-up was performed by one experienced periodontist. All clinical parameters at six sites—mesio-buccal, mid-buccal, disto-buccal, mesio-lingual, mid-lingual, and disto-lingual—were recorded for each implant. In addition, full-mouth periodontal charts were recorded, and the full-mouth plaque score (FMPS) and full-mouth bleeding score (FMBS) on probing were calculated.

2.7.2 | Biological and mechanical complications

Any adverse events that occurred during the follow-up period were recorded. Biological complications included peri-implant mucositis and peri-implantitis. Peri-implant mucositis was defined as bleeding on probing and/or suppuration on gentle probing, with or without increased PD compared to previous examinations, and the absence of bone loss after the initial bone remodelling. Peri-implantitis was defined as bleeding on probing and/or suppuration, increased PD compared to previous examinations, and the occurrence of bone loss after the initial bone remodelling (Berglundh et al., 2018).

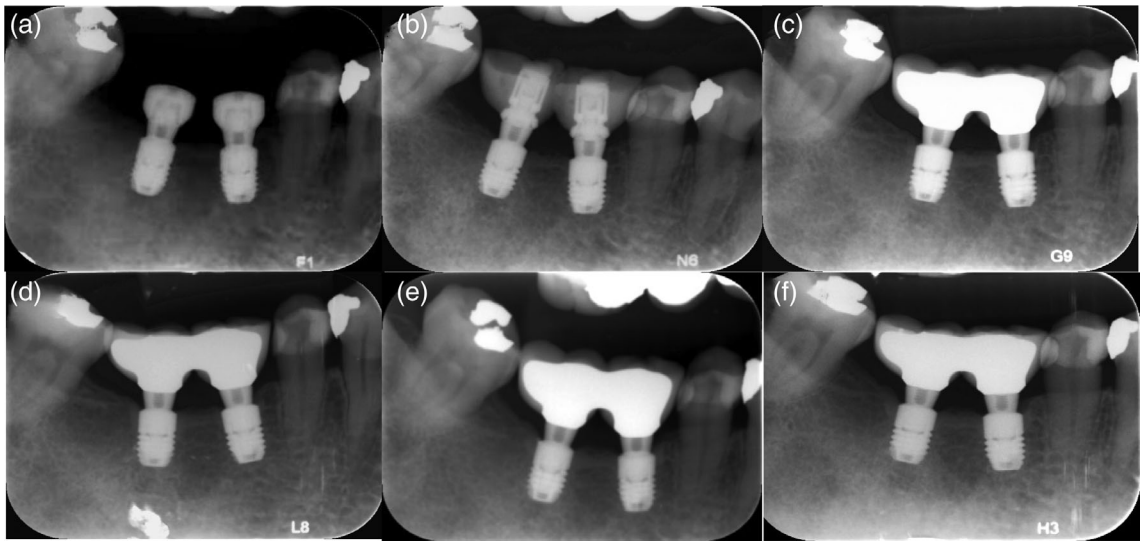

FIGURE 1 Radiograph taken at (a) implant placement, (b) provisional prosthesis delivery (loading, baseline), and (c) definitive prosthesis delivery (6 months after loading), (d) 1 year after loading, (e) 3 years after loading, and (f) 5 years after loading

Prosthesis complications were also recorded, including screw loosening or fractures and veneer fractures. The survival and success rates of the restorations were assessed via intra-oral visual and tactile control of the restoration surface based on the modified US Public Health Service criteria (Cvar & Ryge, 2005), as previously reported (Spies et al., 2018). Restorations with minor chipping, small-area occlusal roughness, slightly soundable restoration margins, minimal contour deficiencies, and tolerable mismatch in colour were regarded as successful.

2.7.3 | Implant survival and success rates

Implant survival was defined as implants that were in place and functioning at the time of follow-up. Implant success was based on the following criteria: no pain or tenderness on function; no mobility; less than 2 mm radiographic bone loss since initial surgery; and no suppuration (Misch et al., 2008).

2.8 | Statistical analysis

Statistical analysis was performed using the SPSS Statistics software 26.0 (IBM Corp., Armonk, NY, USA).

The results of the clinical parameters and MBL are presented using descriptive methods, for example, mean, median, and standard deviation (SD). In regard to patient-level descriptive analysis, mean MBL and PD values of all implants were calculated. BOP over any implant in a patient was considered BOP(+). Plaque detected at any site over any implant was considered as the presence of plaque. The intra- and inter-examiner reliability of MBL were assessed using the intra-class correlation coefficient (ICC). A generalized linear mixed model was used to analyse MBL changes at the implant level and their correlations with the clinical parameters. Correlations between implants within the same patient were considered a random effect. The level of significance was set at $p = .05$ for all comparisons.

All patients with previously reported failures (eight implants in four patients) and two patients (four implants) with unqualified imaging examinations were excluded from the final radiographic analysis; thus, a total of 12 implants in six patients were excluded. The final radiographic analysis included 83 implants in 39 subjects. All patients who completed the 5-year follow-up were enrolled in the analysis of clinical variables, such as the presence of plaque, PD, and BOP.

3 | RESULTS

Based on the inclusion and exclusion criteria mentioned above, 45 patients (95 implants) were enrolled in the clinical trial (17 males and 28 females; mean age: 53 years; range: 26–73 years).

Sixty-four implants were placed in the mandible and 31 in the maxilla. Over the study period, one patient died of cancer shortly before completion of the 3-year follow-up, while one patient relocated to another city and was followed up by telephone at the 5-year follow-up. The remaining 43 patients with 86 implants completed the 5-year evaluation. The drop-out rate was 4.65% (2/45). The patient characteristics and clinical parameters are shown in Table 1.

3.1 | Primary outcome

The intra- and inter-examiner reliability of the MBL values were assessed using the ICC; this resulted in reliability scores of 0.99 and 0.95 for the two examiners, and 0.89 for inter-examiner reliability. The MBL values at various visits are shown in Table 2, and changes in

TABLE 1 Patient characteristics

Description of patient characteristics and clinical parameters No. of patients	
Total	**45**
Patients (implants)	
Centre 1	20 (44)
Centre 2	14 (25)
Centre 3	11 (26)
Gender	
Female	28
Male	17
Age (years)	
Mean	53
Min	26
Max	73
Smoking status[a] (no. of patients)	
Non-smoker	40
Habitual	1
Occasional	1
Ex-smoker	3
Oral examination (no. of patients)	
Abnormal jaw relations	1
Bruxism	2
Edentulous period (months)	
Mean	74
Min.	4
Max.	240
Reason for tooth loss (tooth number/patient number)	
Caries/endodontic	65/32
Periodontitis	29/13
Trauma	1/1
Periodontal condition[b] (no. of patients)	
Periodontitis	35
Stage II	16
Stage III	14
Stage IV	5
Grade B	28
Grade C	7
Plaque-induced gingivitis	10
Implant location (no. of implant sites)	
Maxilla	31 (13 in premolars and 18 in molars)
Mandible	64 (11 in premolars and 53 in molars)
Bone quality[c] (no. of implant sites)	
2	60
3	33
4	2

[a]Smoking status: Habitual smoking was defined as 1–10 cigarettes per day; occasional smoking was defined as smoking at least once a week, but not daily.
[b]The periodontal condition was assessed according to the 2018 new classification of periodontal diseases and conditions.
[c]Bone quality was assessed according to Lekholm and Zarb (1985).

these values over time are presented in Table 3. During the bone remodelling period (between IP and T0), there was a slight decrease in the mean MBL of 0.12 ± 0.19 mm at the patient level. From T0 to 6 months and at 1, 2, 3, and 5 years after loading, the MBL changes remained stable, with small changes of −0.04 ± 0.08, −0.05 ± 0.11, −0.05 ± 0.14, −0.06 ± 0.13, and −0.04 ± 0.14 mm, respectively.

Overall, 16% of the implants showed no MBL changes, while 30% showed bone gain over the 5-year period. There was no significant difference in MBL changes between the maxilla and the mandible (Figure 2). In the analysis using the generalized linear mixed model, MBL remained stable through the 5-year follow-up (Table 4). The presence of plaque, BOP, and a mandibular implant were associated with increased MBL changes but were not statistically significant. MBL changes increased with increased PD, but the changes (0.04 mm) were minimal and considered clinically non-significant.

3.2 | Secondary outcomes

3.2.1 | Clinical characteristics

Based on the initial full-mouth periodontal charts, 35 patients were diagnosed with periodontitis. Periodontal treatment was provided before the clinical trial. The periodontal parameters remained stable at the 5-year follow-up, with FMPS and FMBS values of 29.5% and 12.7%, respectively.

Table 5 shows peri-implant clinical parameters. Detectable plaque was present in 50% of the patients at T0, and varied between 27.5% and 43.2% during the 5-year follow-up period. The percentages of patients with BOP were 30.0%, 30.0%, 42.5%, 40.0%, 55.0%, and 29.4% at the follow-up time points, respectively. The mean PD value of all implant sites at 5 years after loading was 2.41 ± 0.46 mm at the patient level, which is slightly higher than the PD recorded at T0 (2.20 ± 0.76 mm).

3.2.2 | Biological and mechanical complications

Peri-implant mucositis was observed in 30.0%, 42.5%, 40.0%, 55.0%, and 29.4% of the implants at 6 months and at 1, 2, 3, and 5 years after loading, respectively. Three implants in three patients were diagnosed with peri-implantitis, resulting in a prevalence of peri-implantitis of 7.0% (3/43) at the patient level and 3.5% (3/86) at the implant level over the 5-year follow-up period.

In total, eight implants in six patients exhibited mechanical complications. Minor chipping occurred in seven implants: one at 6–12 months after loading, one at 2–3 years after loading, and five at 3–5 years after loading. In addition, one severe veneer fracture occurred at 3–5 years after loading, which required prosthesis replacement.

The total mechanical complication rate at the 5-year follow-up was 14.0% (6/43), while the restoration success rate was 97.7% (42/43).

TABLE 2 Marginal bone levels at each visit

	IP	T0	T6	T12	T24	T36	T60
Patient level							
N	39	39	39	39	38	38	34
Mean ± SD (mm)	−0.20 ± 0.15	−0.08 ± 0.19	−0.04 ± 0.15	−0.03 ± 0.15	−0.02 ± 0.21	−0.02 ± 0.19	−0.01 ± 0.21
Median (mm)	−0.20	−0.08	−0.06	0.00	−0.05	−0.05	−0.04
Min.;Max. (mm)	−0.47;0.09	−0.33;0.77	−0.33;0.62	−0.26;0.63	−0.33;0.99	−0.28;0.92	−0.40;0.86
Implant level							
N	83	83	83	83	80	81	74
Mean ± SD (mm)	−0.19 ± 0.18	−0.07 ± 0.22	−0.04 ± 0.19	−0.03 ± 0.19	−0.02 ± 0.24	−0.02 ± 0.23	−0.01 ± 0.26
Median (mm)	−0.20	−0.08	0.00	0.00	0.00	0.00	0.00
Min.;Max. (mm)	−0.54;0.27	−0.41;0.97	−0.53;0.86	−0.51;0.91	−0.45;1.32	−0.49;1.24	−0.63;1.33

Note: Negative values indicate reference point below the coronal bone-to-implant contact, while positive values indicate reference point over the coronal bone-to-implant contact.
Abbreviation: IP, implant placement; T0, loading; T6, T12, T24, T36, and T60 denote 6, 12, 24, 36, and 60 months after loading.

TABLE 3 Marginal bone level changes

	IP to T0	T0 to T6	T0 to T12	T0 to T24	T0 to T36	T0 to T60
Patient level						
N	39	39	39	38	38	34
Mean ± SD (mm)	−0.12 ± 0.19	−0.04 ± 0.08	−0.05 ± 0.11	−0.05 ± 0.14	−0.06 ± 0.13	−0.04 ± 0.14
Median (mm)	−0.11	−0.04	−0.03	−0.03	−0.02	−0.06
Min.; Max. (mm)	−1.09;0.09	−0.20;0.15	−0.35;0.15	−0.41;0.18	−0.36;0.19	−0.48;0.16
Implant level						
N	83	83	83	80	81	74
Mean ± SD (mm)	−0.12 ± 0.21	−0.04 ± 0.11	−0.05 ± 0.13	−0.05 ± 0.17	−0.05 ± 0.16	−0.07 ± 0.20
Median (mm)	−0.05	0.00	0.00	0.00	−0.01	0.00
Min.;Max. (mm)	−1.30;0.18	−0.37,0.19	−0.41,0.31	−0.71,0.33	−0.41;0.38	−0.77;0.57

Note: Negative values indicate bone loss, while positive values indicate bone gain.

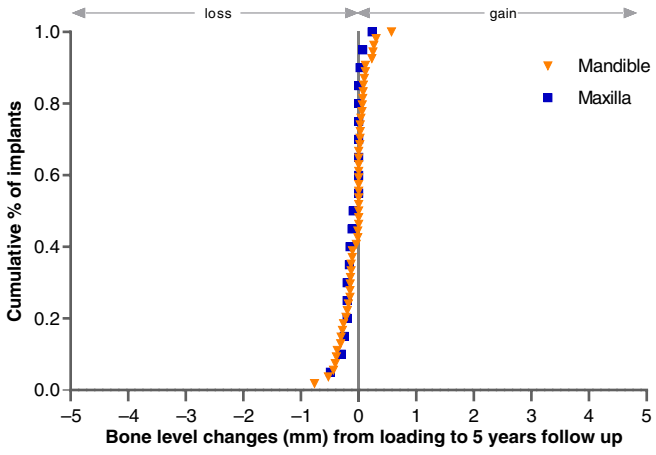

FIGURE 2 Cumulative plot of changes in marginal bone level from loading to 5 years after loading

3.2.3 | Implant survival and success

Two patients with four implants were lost until the final follow-up visit. Five implants in five patients failed, resulting in an implant survival rate of 88.4% (38/43) at the patient level and 94.5% (86/91) at the implant level. Among the five lost implants, four were lost at the time of impression because of obvious mobility and one was removed at the 5-year visit because of severe peri-implantitis. The four implants lost before loading were all in the mandible, while the one lost after loading was in the maxilla. Another implant rotated at the time of impression, at 5 weeks after the surgery, but osseointegrated with a prolonged healing time of 5 months; it was then restored. This implant was considered a success and was included in the clinical, but not in the radiographic, analysis.

Based on the implant success criteria, the success rate was 88.4% (38/43) at the patient level and 94.5% (86/91) at the implant level.

TABLE 4 Multivariable analysis of marginal bone level changes (generalized linear mixed model)

Parameter	Coefficient (95% CI)	*p* value
Mixed effect		
Visit time		
IP–T0	−0.04 (−0.10, 0.01)	0.13
T0–T6	0.05 (−0.01, 0.10)	0.11
T0–T12	0.03 (−0.03, 0.09)	0.30
T0–T24	0.03 (−0.03, 0.09)	0.29
T0–T36	0.04 (−0.01, 0.10)	0.10
T0–T60	Reference	
PD	**−0.04 (−0.07, −0.01)**	**0.02**
BOP		
BOP (−)	0.01 (−0.03, 0.05)	0.64
BOP (+)	Reference	
Presence of plaque		
Not present	0.023 (−0.02, 0.06)	0.256
Present	Reference	
Jaw		
Maxilla	0.03 (−0.04, 0.10)	0.39
Mandible	Reference	
Random effect		
Intercept	**0.01 (0.00, 0.01)**	**0.00**
Var (Visit time)	0.00 (0.00, 0.01)	0.24

Note: Negative values indicate bone loss greater than the reference, while positive values indicate bone loss less than the reference.
Significant associations are highlighted in bold.
Abbreviations: BOP, bleeding on probing; IP, implant placement; PD, probing depth.

4 | DISCUSSION

This prospective study demonstrated that 6-mm short implants with splinted crowns in the posterior region resulted in a mean MBL change of 0.04 ± 0.14 mm, a survival rate of 88.4% and a success rate of 88.4% at the patient level, and stable peri-implant soft tissues. Mean MBL changes over the 5-year follow-up were minimal and not statistically significant. Our results are in agreement with those of previous 5-year longitudinal studies that used the same 6-mm implant system for early loading with splinted crowns (Guljé et al., 2013; Gulje et al., 2021), which also reported minimal MBL changes of 0.01 ± 0.45 mm.

Implant survival rates in this study were consistent with previous studies on short implants with at least 5 years of loading (Rossi et al., 2015; Thoma et al., 2018). However, a meta-analysis showed that short implants (≤6 mm) had survival rates between 86.7% and 100%, with higher variability and lower predictability compared to longer implants (95%–100%) (Papaspyridakos et al., 2018). In addition, short implants (≤6 mm) may present a greater risk for delayed failure. Another meta-analysis, which investigated the effects of function time on the predictability of short dental implants, also demonstrated that failure rates were higher in short implants that had been in function for more than 3 years compared to those that had been in function for less than 3 years (Vazouras et al., 2020).

Short implants were recommended with wide diameter by some studies (Petrie & Williams, 2005; Raaj et al., 2019). A recent randomized clinical trial compared short implants with long implants combined with sinus floor elevation in moderately atrophic posterior maxillae (Shi et al., 2019). The results demonstrated that the survival rate of short implants with wider diameter (4.8 mm) was higher than that of short implants with narrow diameter (4.1 mm). Another study,

TABLE 5 Clinical parameters for probing depth (PD), bleeding on probing (BOP), and presence of plaque at the patient level and at the implant level

Variable	T0	T6	T12	T24	T36	T60
Patient level						
PD (mm)						
Mean ± SD	2.20 ± 0.76	2.48 ± 0.58	2.27 ± 0.56	2.42 ± 0.58	2.72 ± 0.74	2.41 ± 0.46
Median	2.00	2.50	2.25	2.42	2.63	2.33
Min; Max	1.00;3.88	1.25;3.67	1.13;3.63	1.38;3.75	1.50;4.75	1.50;3.75
BOP (%)	30.0	30.0	42.5	40.0	55.0	29.4
Presence of plaque (%)	50	43.2	40	27.5	46.2	38.5
Implant level						
PD (mm)						
Mean ± SD	2.21 ± 0.81	2.50 ± 0.62	2.26 ± 0.62	2.41 ± 0.67	2.71 ± 0.79	2.41 ± 0.68
Median	2.00	2.50	2.25	2.50	2.50	2.33
Min.; Max.	1.00;4.25	1.25;4.00	1.00;4.00	1.00;4.50	1.25;5.75	1.33;4.00
BOP (%)	26.2	26.0	25.9	37.6	50.6	22.8
Presence of plaque (%)	50	40.3	29.4	22.4	42.2	32.9

which compared regular (4.3 mm) and wider implants (5–6 mm) over 3–6 years, found that the wider implants had lower failure rates, but the MBL values were similar in both implant types (Mendonca et al., 2017). A meta-analysis of prospective clinical trials found that the implant width (3.5/4.0/4.1/4.8/5.1 mm) did not significantly affect the survival rates of short implants (Monje et al., 2013). To the best of our knowledge, it remains uncertain whether implant width has any significant effect. In recent studies with 2–5 years of follow-up, short implants with a diameter of 4.0 mm performed well (Pieri et al., 2012; Thoma et al., 2018; Felice et al., 2019). Further long-term prospective studies on this issue are needed.

In the present study, all restorations were splinted with two or three implants. Several studies have suggested that, in the posterior region, splinted restoration should be considered if short implants are used (ten Bruggenkate et al., 1998; Misch et al., 2005; Renouard & Nisand, 2006; Draenert et al., 2012; Vazouras et al., 2020). However, single crowns supported by 6-mm short implants have been used in several studies with predictable clinical outcomes (Rossi et al., 2015; Thoma et al., 2018; Guljé et al., 2019a, 2019b). In those studies, short implants had survival rates and MBL similar to those of longer implants. The effects of splinted and non-splinted prostheses on the clinical outcomes of 6-mm short implants and longer implants were evaluated in a split-mouth study (Clelland et al., 2016). It was found that peri-implant MBL values around splinted and non-splinted implants were similar for the short and longer implants, but all incidences of screw loosening occurred in non-splinted prostheses. In our study, no screw loosening could be observed during the follow-up period and the incidence of veneer fractures was 14.0% at the final visit. The incidence of technical complications was much lower than reported for single-crown restorations in another study (47.7%) (Thoma et al., 2018). However, splinted crowns prevent evaluation of individual implant mobility, and implant assessment must rely on radiographs and clinical signs and symptoms in these cases.

In the present study, four implant failures occurred before loading and one was lost at the 5-year visit after loading because of peri-implantitis. All five patients who lost an implant had a history of periodontitis. Among the four early failures, the possible risk factors included a history of severe periodontitis, a history of smoking, poor bone quality (type IV), and a history of diabetes mellitus. Hence, the early failures may have been influenced by confounding factors. The late failure caused by peri-implantitis was also associated with a history of periodontitis and heavy smoking (the patient was an ex-smoker at the time of enrollment but reverted to smoking 20–30 cigarettes/day at approximately 1 year after surgery). In the consensus report of the 2018 World Workshop on the classification of periodontal and peri-implant diseases and conditions, it was stated that the incidence of peri-implantitis was higher and long-term success rates were lower in patients with a history of periodontitis and smoking (Schwarz et al., 2018). This has also been established by several previous studies (Karoussis et al., 2003; Van der Weijden et al., 2005; Ferreira et al., 2006; Sousa et al., 2016). The impact of peri-implantitis on short implants, with a limited intra-bony portion, is more significant than on longer implants. Therefore, periodontitis control and maintenance therapy are critical for the long-term survival of short implants. In our study, approximately 80% of the patients were diagnosed with periodontitis, of which 54.3% were stage III/IV. Initial FMBS was 91.6% in the patients. All patients received standard periodontal therapy before implant placement. After treatment, the mean FMBS decreased to 45.1%, and there was no site with a PD >5 mm. During the follow-up period, all patients received regular maintenance at every 6–12 months. After a 5-year follow-up, the FMPS and FMBS values were 29.5% and 12.7%, respectively, which are significant improvements compared to the values after the initial periodontal therapy. However, these full-mouth clinical parameters were still higher than those reported in a similar study (Rossi et al., 2015). At the patient level, the mean percentage of plaque was 38.5% and the mean BOP was 29.4% at the 5-year follow-up. The mean PD value at implant sites was 2.41 ± 0.46 mm. These findings are consistent with those of other similar studies (Abduljabbar et al., 2018; Shi et al., 2019). These results may be attributable to strict maintenance by professional periodontists and reinforced oral hygiene instructions at each visit.

The limitations of this study should also be considered while interpreting the results. The main limitation was that splinted crowns make the evaluation of individual implant mobility difficult. In addition, this was not a randomized controlled study, and the results should be interpreted cautiously.

5 | CONCLUSION

Over a 5-year period, 6-mm implants supporting early loaded splinted crowns in maxillary or mandibular posterior regions showed stable MBL values and acceptable technical and biological complication rates. However, the use of shorter implants is limited to certain clinical situations and requires regular periodontal maintenance.

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ETHICS STATEMENT

The study was approved by the Ethics Committee of Peking University Medical Center and Peking University School of Stomatology with the study number: IRB00001052-11003 and PKUSSIRB-201628064.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Investigation, *data curation*, *formal analysis*, *visualization*, *writing - original draft preparation*: Huiping Sui. *Methodology*, *investigation*: Zhihui Tang and Xiao Zhang. *Data curation*: Diyuan Wei. *Conceptualization*, *methodology*, *project administration*, *writing - review and editing*: Huanxin Meng. *Funding acquisition*, *conceptualization*, *methodology*, *supervision*, *project administration*, *writing - review and editing*: Jie Han.

DATA AVAILABILITY STATEMENT

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

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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