

Hong-Chang Lai
 Mi-Si Si
 Long-Fei Zhuang
 Hui Shen
 Yue-lian Liu
 Daniel Wismeijer

Long-term outcomes of short dental implants supporting single crowns in posterior region: a clinical retrospective study of 5–10 years

Authors' affiliations:

Hong-Chang Lai, Mi-Si Si, Department of Oral and Maxillo-facial Implantology, Shanghai Ninth People's Hospital, School of Medicine, Shanghai Jiaotong University, Shanghai, China
 Long-Fei Zhuang, Faculty of Dentistry, the University of Hong Kong, Hong Kong, China
 Hui Shen, Arrail Dental Clinic, Shanghai, China
 Yue-lian Liu, Daniel Wismeijer, Oral Function and Restorative Dentistry, Section Oral Implantology and Prosthetic Dentistry, LA Amsterdam, The Netherlands

Corresponding author:

Prof. Hong-Chang Lai
 Department of Oral and Maxillo-facial Implantology, Shanghai Ninth People's Hospital, School of Medicine, Shanghai Jiaotong University No. 639 Zhi-Zao-Ju Road, Shanghai, 200011, China
 Tel.: +86 21 13501881537
 Fax: +86 21 53073068
 e-mail: lhc9@hotmail.com

Key words: complications, dental implant, short implant, single crown, survival analysis

Abstract

Objective: Aimed to evaluate the long-term clinical and radiographic outcomes of short implants supporting single crowns in the posterior regions.

Material and methods: A retrospective study design was adopted. The clinical and radiographic data of 231 short implants (intra-bony length ≤ 8 mm) supporting single crowns in 168 patients, were collected after 5–10 (mean 7.22) years' follow-up. Implant and prosthesis failures, peri-implant marginal bone loss, biological and technical complications were evaluated. The influence factors on implant failure were studied.

Results: In total 4 implants and 11 prostheses failed. The 10-year (5-year) cumulative survival rate was 98.3% (98.7%) for implant-based analysis and 97.6% (98.2%) for patient-based analysis. The short implants placed in type IV bone yielded more failures than in type I–III and presented a survival rate of 94.0%. The 10-year survival rate of the prostheses was 95.2%. The mean marginal bone loss between implant installation and the 10 years' follow-up visit was 0.63 ± 0.68 mm. The marginal bone loss between the first and 5th year was minimal (0.05 ± 0.10 mm and not statistically significant). 18 (7.8%) implants were exposed to biological complications, whereas 29 (12.6%) implants were involved in technical complications.

Conclusions: High survival rates for both the implants and the prostheses could be achieved after 5–10 years for short implants supporting single crowns, without severe marginal bone loss and complications. One may conclude that a single crown supported by a short implant is a predictable treatment modality. However, short implants in type IV bone sites should be applied with caution.

Dental implant therapy has now been widely accepted by both the dentists and patients as an efficacious method for replacing missing teeth in totally and partially edentulous patients. However, in the past, a minimal bone height of 10 mm is required for implant installation (Andersson et al. 1995). Therefore, reduced alveolar bone height due to post-extraction atrophy and maxillary sinus pneumatization becomes a major challenge, especially in posterior regions. The insufficient residual bone height not only limits the application of implant therapy, but also increases the probability of invasive damage to some anatomical structures, such as the inferior alveolar nerve, maxillary sinus and nasal cavity (das Neves et al. 2006).

As a solution, the bone augmentation techniques have been suggested. Although these approaches including onlay bone grafts,

guided bone regeneration (GBR) (Merli et al. 2007; Fontana et al. 2008), maxillary sinus elevation (Pjetursson et al. 2008; Tan et al. 2008) and distraction osteogenesis (DO) (Chiapasco et al. 2004), have been proved effective in regaining bone volume, they are hardly accepted by the patients because of the multiple complications and morbidity after surgery, the prolonged treatment duration and the high extra costs.

As an alternative, short implants are being increasingly used in extremely resorbed posterior region. The definitions of short implants varied in the literature. Authors defined implant length less than 11 mm (das Neves et al. 2006), 10 mm (Morand & Irinakis 2007) or 8 mm (Renouard & Nisand 2006) as short implants. Telleman et al. (2011) argued that, because an implant can be placed at different horizontal levels, a short implant should be defined as an implant with

Date:

Accepted 25 February 2012

To cite this article:

Lai H-C, Si M-S, Zhuang L-F, Shen H, Liu Y-I, Wismeijer D. Long-term outcomes of short dental implants supporting single crowns in posterior region: a clinical retrospective study of 5–10 years. *Clin. Oral Impl. Res.* 00, 2012, 1–8
 doi: 10.1111/j.1600-0501.2012.02452.x

a designed intra-bony length of 8 mm or less (Renouard & Nisand 2006).

In the past, short implants have been associated with lower survival rates and unpredictable long-term outcomes (Bahat 1993; Winkler et al. 2000; Pierrisnard et al. 2003; Weng et al. 2003). However, the improvement of implant systems, especially the development of surface modification techniques, could give chance to enhance the osseointegration of the implants with limited intra-bony length. Recent studies have indicated that short implants could present a similar survival rate to conventional implants (Glantz & Nilner 1998; Griffin & Cheung 2004; Nedir et al. 2004; Misch et al. 2006; Anitua et al. 2008; Anitua & Orive 2010; Telleman et al. 2011). The implant length was no longer considered a crucial factor in influencing implant success (Testori et al. 2001; Romeo et al. 2002; Stellingsma et al. 2003; Renouard & Nisand 2006).

While success and survival of the short implants are widely investigated, the studies on prosthetic aspects are limited. The majority of clinical studies on short implants only focused on implant survival without providing information about possible complications and restorative outcomes. In addition, little is known about the influence of prosthesis design on short implant survival. For comprehensive outcomes of these studies, the long-term prognosis of not only the short implants but also the prostheses should be acquired.

Single crown restorations are one of the most frequent therapies in implant dentistry. Single units offer a more comfortable prosthetic approach with better emergence profiles and better oral hygiene access than other fixed partial prostheses (Solnit & Schneider 1998). However, it has been recommended to splint short implants with the longer ones to avoid unfavorable stress (Rangert et al. 1997). In a recent 2-year clinical study (Rossi et al. 2010), short implants with a moderately rough surface supporting single crowns yielded high implant survival rates and moderate loss of marginal bone. Nevertheless, the long-term observation on short implants supporting single crown prostheses in the posterior region is still missing. The details of prosthesis-related complications of this modality are still unknown.

In the present study, we collected the clinical data of patients followed 5–10 years with short implants (intra-bony length of ≤ 8 mm) supporting single crowns. We analyzed the implant and prosthesis failures, prosthesis-related complications and marginal bone loss, in the aim of evaluating the long-term out-

comes of the short SLA implants with single crown restorations.

Materials and methods

Patient selection

168 patients during the period from January 2001 to December 2005, at the Department of Oral and Maxillofacial Implantology, Shanghai Ninth People's Hospital, Shanghai Jiaotong University, China, were evaluated in the present study.

The following inclusion criteria were applied: (1) Age ≥ 18 years, (2) partial edentulism in the posterior region, (3) at least 6 weeks of healing after tooth extraction, (4) installation of Straumann® SLA implants (institute Straumann AG, Waldenburg, Switzerland) with intra-bony length of ≤ 8 mm, without bone augmentation, (5) restored with single crowns 3–6 months after surgery, (6) in good systemic and oral health, (7) willing to provide informed consent.

The patients were excluded on the basis of: (1) uncontrolled diabetes mellitus or other systemic disorders, (2) uncontrolled periodontal conditions or other oral disorders, (3) insufficient residual bone quality to achieve implant stability, (4) previous bone grafting at the surgical site.

After screening, 19 patients were excluded according to the criteria. The smoking patients were not excluded but were informed that smoking is a risk factor of implant failure.

According to the criteria, 168 patients (106 male and 62 female), 23–72 years old (mean age 45.9), with 231 short implants supporting single crowns in the posterior region were enrolled. The study was conducted in accordance with the Helsinki declaration of 1975 as revised in 2008, and all patients signed the informed consent form.

Pre-surgical preparation

Before the implant installation, all patients received examinations regarding periodontal diseases, caries and soft tissue disorders. They also received appropriate treatment and oral hygiene instruction. Panoramic radiographs or computer tomography (CT) scans were obtained before implant installation.

Surgical procedure

Under local infiltration anesthesia (Articain® with adrenaline 1 : 100,000), implants were installed according to the Straumann® implant surgery protocol by two experienced implant surgeons. SLA implants with the

length of 8 mm or 6 mm were placed in the prepared sites using a hand ratchet without pre-tapping. All implants achieved good primary stability. A non-submerged protocol in a one-stage procedure was performed. A panoramic and a periapical radiograph were taken of all the cases directly after implant surgery (baseline).

Post-surgical procedure

Anti-inflammatory cefradine (500 mg, four times a day for 5 days; Xinya Co., Shanghai, China) and metronidazole (400 mg, three times a day for 5 days; Xinyiwanxiang, Shanghai, China) were prescribed after surgery. Non-steroidal anti-inflammatory agents were prescribed for post-surgical analgesia. A 0.12% chlorhexidine oral rinse was prescribed for 30 s twice a day for 7 days. Sutures were removed after 7–10 days. No provisional prosthesis was allowed to be worn during the healing period.

Restorative procedure

After 6–18 weeks of healing, the patients were recalled for the restorative treatment. The prosthetic procedures were carried out by three professional prosthodontists. A panoramic and a periapical radiograph were taken to examine whether there was a continued radiolucency around the implant body. Abutments were tightened with a torque of 35 N cm. If the implants were stable, the impressions were taken. Metal-ceramic single-crown prostheses were fabricated and delivered to the patients after about 7–10 days. All the crowns were cement-retained.

Follow-up examination

The patients were recalled for radiographic and clinical examinations every 6–12 month. During each visit, the clinical assessment of implants, prostheses and peri-implant tissues were respectively conducted by a surgeon and a prosthodontist, who were not involved in the treatment of the patients. A panoramic and a periapical radiograph were taken to evaluate the bone level and peri-implant radiolucency. For the patients experiencing implant loss or other complications, data related to the causes were collected.

Outcome measurements

The outcome measurements of short implants supporting single crowns in posterior region were as follows:

- (1). Implant failure: implant loss, mobility or removal in case of progressive marginal

bone loss, severe peri-implant infection or implant fracture. The implant failures were classified into two types: the early failures (or initial failures) before loading and the late failures after loading. The implant survivals were determined by the same method suggested by Buser et al. (1997) and Cochran et al. (2002): (a) absence of clinically detectable implant mobility, (b) absence of pain and subjective discomfort, (c) absence of peri-implant infection, (d) absence of continuous radiolucency around the implant.

- (2). Prosthesis failure: prosthesis loss or remake because of implant failure or other complications. The single crown survival was defined as the single crowns remaining *in situ* with or without modification for the observation period (Jung et al. 2008).
- (3). Peri-implant marginal bone loss was evaluated on radiographs taken at implant placement, at delivery of the prostheses and at every follow-up visit. The location of the marginal bone levels in relation to the implant shoulder was assessed at the mesial and the distal aspect using a software program (SIDEXIS 1.12; Sirona Dental System GmbH, Bensheim, Germany). Some reference lines were drawn like Fig. 1: (a) Implant longitudinal axis, (b) implant collar line: a line vertical to (a), and at the most coronal level of the implant collar, (c) a line vertical to (a), and at the most coronal level of bone-to-implant contact at the mesial site, (d) the same as (c), at the distal site. The crestal

marginal bone level was the distance parallel to the implant axis between (b) and (c) at the mesial site or the distance between (b) and (d) at the distal site. The radiographic assessment results of 1-year, 5-year and 10-year follow-up visits were compared with those at implant installation to calculate the marginal bone loss.

- (4). Complications were divided into two types. (a) Biological complications including the disturbances in the function of the implant characterized by a biological process affecting the supporting tissues and structures e.g., severe pain or swelling after surgery, peri-implant infection, discomfort on occlusion, nerve dysfunction, and other soft tissue complications et al. The threshold to define a peri-implantitis was set at a probing pocket depth of ≥ 6 mm and bleeding on probing or pus secretion. (b) Technical complications denoted mechanical damage of implants, implant components and supra-structures, including amongst others, fracture of abutment, loss of retention, fracture of porcelain, loosening of screws. Complications were managed during the recall session. In case of a peri-implantitis, a cumulative interceptive anti-infective treatment protocol was applied (Mombelli & Lang 1998). Minor technical complications as screw loosening were managed during the follow-up visit. Additional appointments were arranged when repair or major complications required new treatment planning.

Statistical analysis

The descriptive and the quantitative data were record in an individual chart for later analysis. SPSS Software (SPSS 17.0; SPSS Inc., Chicago, IL, USA) was applied to conduct the statistical analyses. Descriptive statistics were performed and absolute and relative frequency distributions were calculated for qualitative variables. Mean and standard deviation were calculated for quantitative variables to assess the radiographic bone-level parameters, and the data compared at different time points was analyzed by an unpaired *t*-test. The implant and prosthesis survival rates were assessed by patient-based analysis and implant-based analysis respectively. In both types of analysis, the implant survival as a function of the time was analyzed using a life table analysis. Fisher's exact test was applied to assess the influence of variables on survival rates. Variables including age at surgery (categorized into three categories: 20–34 years, 35–55 years, and >55 years), gender

and smoking status (smokers or non-smokers) were analyzed at the patient-level. Variables including implant length (8 mm or 6 mm), implant diameter ($\Phi 4.1$ mm or $\Phi 4.8$ mm), bone type and implant position (mandible or maxilla) were analyzed at the implant-level. The bone types were classified by tactile evaluation during drilling and radiographic assessment according to the criteria of Lekholm & Zarb (1985) index. Bone type I and III were considered as one group when statistical analysis was performed, because of the difficulty to distinguish between the two types in the clinic. Smokers were defined as patients who took cigarettes during the follow-up period without considering the amount. The significance level was set at 0.05.

Results

168 patients (106 male and 62 female, mean age 45.9 years) were eligible for the present study. 231 implants were installed. The average healing time before loading was 10.5 weeks, the average follow-up time was 7.22 years.

Implant survival rate and implant failure

During the 10-year follow-up, four implants in four patients were lost. A cumulative survival rate of 98.3% (implant-based) and 97.6% (patient-based) were achieved at 10-year follow-up. The 5-year cumulative survival rate is 98.7% (implant-based) and 98.2% (patient-based) (Table 1). Two implants with $\Phi 4.1$ mm in mandibular molar sites were lost within the healing period after surgery (early failure). Hence, the early failure rate of short implants in the present study was 0.9%. Another two implants failed after functional loading (Table 2). The life table analysis results are shown in Table 1. The details of the failed implants are recorded in Table 2.

The evaluation of the potential influence of different variables on implant survival is described in Table 3. The frequency of the lengths and diameters of the 231 short implants are also shown in Table 3. The survival rates did not differ significantly with respect to patients' gender, age, smoking status and implant length, implant diameter, implant location, while bone type exhibited significant differences regarding implant failure (Table 3).

Prosthesis failure

229 implants were restored with metal-ceramic single crowns. All the crowns were cemented. A total of 11 (4.8%) crowns failed

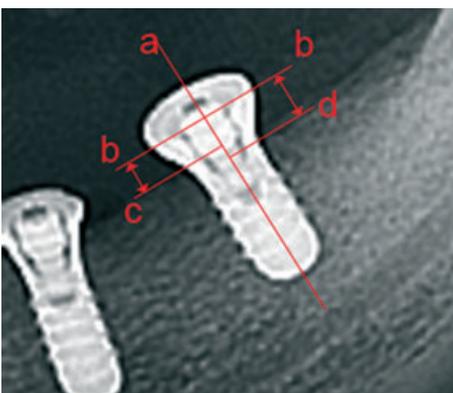


Fig. 1. Crest marginal bone level measured on radiographs. (a) Implant middle axis, (b) implant collar line: a line vertical to (a), and right cross the coronal point of the implant collar, (c) a line vertical to (a), and right cross the coronal point of mesial crest bone-to-implant contact, (d) the same as (c), in the implant distal site. The crestal marginal bone level was the distance between (b) and (c) in the mesial site and the distance between (b) and (d) in the distal site which both parallel to the implant axis.

Table 1. 10-year life table analysis of SLA short implants

Implant-based analysis						Patient-based analysis				
Time interval	Implant numbers	Failure numbers	Survival rates on interval (%)	95% CI (%)	Cumulative survival rates (%)	Patient numbers	Failure numbers	Survival rates on interval (%)	Cumulative survival rates (%)	95% CI (%)
0–1	231	2	99.1	97.3–100	99.3	168	2	98.8	98.8	96.8–100
1–2	229	1	99.6	96.7–100	98.7	166	1	99.4	98.2	96.2–100
2–3	228	0	100	96.7–100	98.7	165	0	100	98.2	96.2–100
3–4	228	0	100	96.7–100	98.7	165	0	100	98.2	96.2–100
4–5	222	0	100	96.7–100	98.7	163	0	100	98.2	96.2–100
5–6	214	0	100	96.7–100	98.7	156	0	100	98.2	96.2–100
6–7	145	1	99.3	96.3–100	98.3	110	1	99.1	97.6	93.7–100
7–8	80	0	100	96.3–100	98.3	65	0	100	97.6	93.7–100
8–9	41	0	100	96.3–100	98.3	36	0	100	97.6	93.7–100
9–10	15	0	100	96.3–100	98.3	12	0	100	97.6	93.7–100

Table 2. Implant failure analysis

Gender	Age (years)	Site	Bone type	Implant diameter (mm)	Implant length (mm)	Smoking status	Time of failure	Cause of failure	Failure type	Final restoration
M	64	47	IV	4.1	8	Non-smoker	3 weeks after surgery	Acute inflammation	Early failure	Short implant-supported prosthesis
F	36	37	IV	4.1	6	Non-smoker	3 months after surgery	Continuous marginal bone loss	Early failure	N/A
F	51	26	IV	4.8	8	Non-smoker	6 months after loading	Implant mobility	Late failure	N/A
M	52	25	III	4.1	8	Smoker	6 years after loading	Peri-implantitis	Late failure	Fixed bridge

Table 3. Analysis of variables

	N	Failures	Survival rate (%)	P-value
Patient-based analysis (N = No. of patients)				
Gender				
Male	106	2	98.5	0.626
Female	62	2	97.9	
Age (years)				1.000
20–34	18	0	100	
35–55	114	3	97.4	
55~	36	1	97.2	
Smoking status				0.535
Smokers	29	1	96.6	
Non-smokers	139	3	97.8	
Implant-based analysis (N = No. of implants)				
Implant length (mm)				1.000
6	33	1	97.0	
8	198	3	98.5	
Implant diameter (mm)				0.419
4.1	182	3	98.4	
4.8	49	1	98.0	
Bone type				0.047*
I	32	0	100	
II&III	148	1	99.3	
IV	50	3	94.0	
Implant Insertion site				1.000
maxilla	110	2	98.2	
mandible	121	2	98.3	

*Statistically significant difference ($P < 0.05$).

during the observation period, two of which were due to implant failures. Nine crowns were remade because of technical complications. The cumulative survival rate of the prostheses was 95.2% in the present study.

Peri-implant marginal bone loss

The mean bone loss between implant installation and the 10-year follow-up visit was 0.63 ± 0.68 mm, while only 0.05 ± 0.01 mm was lost up to the 5-year follow-up (Table 4).

Complications

During implant installation surgery and the following years of observation, 18 (7.8%) implants were exposed to biological complications, whereas 29 (12.6%) implant-supported restorations were involved in technical complications.

No maxillary sinus perforation or permanent mandibular inferior nerve damage occurred. One patient has suffered temporary mental nerve dysfunction during 3 weeks after surgery, and then recovered spontaneously. Two patients went through severe swelling and pain after surgery, one of which resulted in implant failure. 15 (6.5%) implants were diagnosed with peri-implantitis or peri-implant mucositis, two of which resulted in implant failures.

The most frequent technical complication was abutment screw loosening, which occurred in 13 implants during the observation period. One (0.4%) abutment fracture, nine (3.9%) loss of retention and six (2.6%) porcelain fractures occurred. Among the implants and prostheses involved in technical complications, two implants and nine prostheses failed.

Discussion

The present study was designed to evaluate the long-term outcomes of the short implants

Table 4. Peri-implant marginal bone level and bone loss at various visits (mean ± SD)

	Marginal bone level (mm)	Marginal bone loss compared with implant installation (mm)	Marginal bone loss compared with previous visit(mm)
Implant installation	1.70 ± 0.12	—	—
1-year visit	2.25 ± 0.56*	0.55 ± 0.45	0.55 ± 0.45
5-year visit	2.30 ± 0.66*	0.60 ± 0.54	0.05 ± 0.10*
10-year visit	2.33 ± 0.80*	0.63 ± 0.68	0.03 ± 0.14*

*unpaired *t*-test: *P* < 0.01.
 The means of marginal bone level (mm) at 1-year, 5-year, 10-year visit are significantly higher than that at implant installation, but no statistically significant difference has been found between the three.
 The marginal bone loss: (i) between 1-year visit and 5-year visit.(ii) between 5-year visit and 10-year visit, are significantly less than that between 1-year visit and implant installation.

supporting single crowns, based on four aspects: implant survival, prosthesis failure, peri-implant marginal bone loss and complications. The results demonstrated high survival rates of both implants and prostheses, with a minimal loss of marginal bone and a low incidence of complications after 5–10 years.

Our study result showed a high cumulative survival rate of short implants (intra-bony length of ≤ 8 mm) supporting single crowns after 5–10 years: 98.3% (10 years' follow-up) and 98.7% (5 years' follow-up) by implant-based analysis and 97.6% (10 years' follow-up) and 98.2% (5 years' follow-up) by patient-based analysis. The initial failure rate in the present study was only 0.9% (two implants out of 231). This result is in agreement with the long-term observations reporting high survival rates on conventional implants with SLA or other moderately rough surfaces when supporting single-crown prostheses (Mericske-Stern et al. 2001; Romeo et al. 2004; Brägger et al. 2005; Renouard & Nisand 2006). Furthermore, the cumulative survival rate in the present study is a little higher than that reported in the systematic review on conventional implants supporting single crowns. Jung et al. (2008) reviewed that the initial failure rate before loading was 1.9%, and the survival rate was 96.8% after 5 years when referring to conventional implants (intra-bony length of >8 mm) supporting single crowns. The difference may be explained by different inclusion criteria. In that review, different implant systems with different surface modification techniques, different installation and loading protocols were included. All of these factors could influence the implant survivals.

The predictable outcome of short implants supporting single crowns in the posterior regions may be explained as follows. Firstly, the improvements of implant surface modification guarantee superior bone-to-implant contact and more reliable osseointegration

(Cochran et al. 1996, 1998, 2002; Buser et al. 1999, 2004; Rocuzzo et al. 2001; Rocuzzo & Wilson 2002; Sticker et al. 2003; Sul et al. 2009). The surface configuration may have more influence on implant survival than implant length does. Under this precondition, the limitation of short implants should be re-evaluated. It could be presumed that better bone-to-implant contact would be obtained by short implants with newly developed surfaces. Since the area of a rough implant surface is much larger than the smooth one at the microscopic level, even though it seems to be less at the macroscopic level when comparing a short implant to a conventional one. Secondly, the masticatory movement is created by the whole masticatory system. The magnitude of masticatory force is not only loaded on the single prosthesis, but also borne by the entire nature dentition, the mandible and the temporomandibular joint. During the normal chewing process, instantaneous stress distributed on the implant-supported single crown is relatively small. Typical values of bite force are within 50 k and total time of tooth contact in a 24-h period is only about 15 min (Brunski 1992). Thus the mechanical impact is limited because the total time is limited. Moreover, in the posterior region, the loading force on the prosthesis is mostly axial, which is thought to produce less damage to the bone-to-implant surface (Ding et al. 2009). The limited length of short implant may provide enough osseointegrated bone-to-implant surface area to overcome the occlusal force transmitted from the unsplinted supra-structure. This "effective implant length" or "effective bone-to-implant surface" which satisfies the functional needs of the prostheses, is the key to ensure the long-term outcome of the short implants supporting single crowns.

The minimal implant length below which implant failure is certain has not yet been defined. There are few studies evaluating the

different survival rates of short implants with different lengths. In the present study, the 6 mm-long implants presented a high survival rate of 97%, which is comparable to the results reported by Rossi et al. (2010). When comparing the two groups of short implants, no significant difference was found between the implants of 6 mm length and 8 mm length. However, the sample size (*n* = 33) of 6 mm-long implants included in the present study was limited. This result should be interpreted with caution when referring to the influence of different lengths on short implant survival.

It should be emphasized that the low density and poor quality of the bone in implant sites may cause the short implant failure. In the present study, the short implants placed in type IV bone yielded more failures than in type –III significantly, presenting a survival rate of 94.0%. This finding is in line with other reports. Renouard & Nisand (2006) and Nedir et al. (2004) both suggested that the low bone density in the edentulous site was a risk factor for short implant failure. Therefore, the replacement of short implant in type IV should be considered carefully.

From the biomechanical point of view, the occlusal forces during functional loading would mainly be transmitted to the implant neck and distributed to the crestal bone at the first few threads (Griffin & Cheung 2004). Therefore, the peri-implant marginal bone loss becomes an important sign of overloading and unfavorable stress distribution. Other authors also argued that the small amount of marginal bone loss in the first year could be accepted and explained by formation of peri-implant soft tissue attachment, so-called biological width (Berglundh & Lindhe 1996). The amount of marginal bone loss around the implants supporting single crowns in the present study was 0.55 ± 0.45 mm during the first year, and remained stable in the following 5–10 years in the present study. This trend is consistent with the radiographic findings of conventional ITI implants supporting single crowns reported by Mericske-Stern et al. (2001), who concluded that the most changes in the crestal bone level occur in the first year postsurgically. After this, stable adjacent bone levels may be expected around healthy implants. This same trend of crestal bone loss around short implants and conventional implants may represent the same stress-bearing capacity and stress distribution patterns regardless of different supra-structure types. In other words, short implants with the intra-bony length of ≤ 8 mm are sufficient to support

the occlusal forces without undesirable crestal bone resorption even when restored with unsplinted single crowns.

Some authors suggested that the unfavorable crown-to-implant (C/I) ratio of implant supported restoration was the cause of peri-implant marginal bone loss (Rangert et al. 1997; Glantz & Nilner 1998). However, Blanes et al. (2007) found that the implant restoration with C/I ratio between 2 and 3 would be successfully used in the posterior areas of the jaw. Unfortunately, to our knowledge, no study has been involved in assessing whether the C/I ratio has impact on peri-implant bone loss and the implant survival when analyzing short implants with single crown prosthesis. This is also the shortcoming of the present study. C/I ratio should be further discussed in future clinical observations.

Compared to the survival rates of implants placed in the augmented areas, the results of short implants in the present study have obvious advantages. The survival rates of implants placed in augmented sites ranged from 92.1% to 100% for GBR, from 90% to 100% for DO, from 76% to 100% for onlay bone grafts over 1–7 years were reported by Rocchietta et al. (2008). The author's previous study showed that the SLA implants placed in sites with residual bone height around 5 mm after osteotome sinus floor elevation yielded a 5-year cumulative survival rate of 95.71% (Lai et al. 2010), which is much lower than the short implants with the same surfaces installed in the similar sites (98.2% in the maxilla). Tonetti et al. (2008) also highlighted that, bone augmentation procedures can fail and implants placed in these areas do not necessarily enjoy the high long-term survival rates. Hence, the short implants as an alternative could be advocated to solve specific problems.

The advantages of short implant restorations also revealed at the lower complication rate. High percentage and broad spectrum of

complications were reported during or after the bone augmentation treatments: 10–75.7% in DO (Rocchietta et al. 2008), 10–50% in onlay bone graft (Chiapasco et al. 2006), 3.8–19.5% in sinus floor elevation (Pjetursson et al. 2008; Tan et al. 2008). However, in this up to 10-year survey, no sinus membrane perforation or permanent nerve damage occurred. Only two post-surgical dehiscences and one temporary nerve dysfunction was reported. The most common complication was peri-implant diseases (15/18) in the present study, which agreed with the results found by Jung et al. (2008). Brägger et al. (2005) also suggested that the implants with a history of peri-implantitis were at higher risk to fail compared to implants with no biological complications. Our results found the same trend that two in four failed implants had gone through a peri-implant disease. But the question regarding the reason of peri-implant diseases remains open.

29 (12.6%) implant-supported restorations in the present study were involved in technical complications. Two implants and nine prostheses failed subsequently. This result concurs with other studies on unsplinted implant-supported single crowns, but is higher than that of splinted ones (Pjetursson et al. 2004a,b). This may be explained by the different stress distribution on the supra-structure of splinted and unsplinted restorations. In unsplinted single crowns, more stress is transmitted to restoration margins, whereas in splinted restorations, stress is mostly distributed to the implant neck (Nissan et al. 2010). Hence, technical complications like loss of retention and loosening of abutment screws are more frequent in single crowns. Although these complications were reported to increase the risk of supra-structure failures (Brägger et al. 2005), regular visits may avoid further influence on long-term outcomes.

The present study suggests that short implants supporting single crowns could

yield reliable long-term outcomes, but their potential of replacing bone augmentation is still lack of high-level evidence. A recent 1-year randomized clinical trial aimed to compare the 7-mm-long implants and vertical augmentation in posterior mandibles concluded that, short implants might be a preferable choice to vertical ridge augmentation (Felice et al. 2010). However, no randomized clinical trial has been found in the posterior maxilla.

With regard to patients' smoking status, the simple classification adopted in the present study is not sufficient to investigate the dose-effect relationship of smoking and short implant failure. Prospective study should be done to further analyze the influencing factors. In addition, there were no considerations of some factors which may confound the findings, e.g. patients' oral hygiene habits, alcohol intake or periodontal status in the present study. Further study is needed to take these variables into account.

In conclusion, the present study found that a high survival rate of both the implants and the prostheses could be achieved for short SLA implants (intra-bony length of ≤ 8 mm) supporting single crowns, without severe marginal bone loss and complications after 5–10 years. This predictable use of short implants with single crowns could expand the range of indication and increase patients' acceptance of implant therapy. Caution should be advised when placing a short implant in sites with low bone density.

Acknowledgement: This study has been jointly supported by Science and Technology Commission of Shanghai Municipality (09411955000 & 1052 nm04500), National Natural Science Foundation of China (31070842), and National Basic Research Program of China (2012CB933604).

References

- Andersson, B., Ödman, P. & Carlsson, G.E. (1995) A study of 184 consecutive patients referred for single tooth replacement. *Clinical Oral Implants Research* **6**: 232–237.
- Anitua, E. & Orive, G. (2010) Short implants in maxilla and mandibles: a retrospective study with 1 to 8 Years of follow-up. *Journal of Periodontology* **81**: 819–826.
- Anitua, E., Orive, G., Aguirre, J.J. & Andra, I. (2008) Five-Year Clinical evaluation of short dental implants placed in posterior areas: a retrospective study. *Journal of Periodontology* **79**: 42–48.
- Bahat, O. (1993) Treatment planning and placement of dental implants in the posterior maxillae: report on 732 consecutive Nobelpharma implants. *The International Journal of Oral & Maxillofacial Implants* **8**: 151–161.
- Berglundh, T. & Lindhe, J. (1996) Dimension of the periimplant mucosa. Biological width revisited. *Journal of Clinical Periodontology* **23**: 971–973.
- Blanes, R.J., Bernard, J.P., Blanes, Z.M. & Belsler, U. C. (2007) A 10-year prospective study of ITI dental implants placed in the posterior region. I: clinical and radiographic results. *Clinical Oral Implants Research* **18**: 699–706.
- Brägger, U., Karoussis, I., Persson, R., Pjetursson, B., Salvi, G. & Lang, N. (2005) Technical and biological complications/failures with single crowns and fixed partial dentures on implants: a 10-year prospective cohort study. *Clinical Oral Implants Research* **16**: 326–334.
- Brunski, J.B. (1992) Biomechanical factors affecting the bone-dental implant interface. *Clinical Materials* **3**: 153–201.
- Buser, D., Broggini, N., Wieland, M., Schenk, R.K., Denzer, A.J., Cochran, D.L., Hoffmann, B., Lussi, A. & Steinemann, S.G. (2004) Enhanced bone apposition to a chemically modified SLA

- titanium surface. *Journal of Dental Research* **83**: 529–533.
- Buser, D., Mericske-Stern, R., Bernard, J.P., Behneke, A., Behneke, N., Hirt, H.P., Belsler, U.C. & Lang, N.P. (1997) Long-term evaluation of non-submerged ITI implants. Part 1: 8-year life table analysis of a prospective multi-center study with 2359 implants. *Clinical Oral Implants Research* **8**: 161–172.
- Buser, D., Nydegger, T., Oxland, T., Cochran, D.L., Schenk, R.K., Hirt, H.P., Snetivy, D. & Nolte, L. P. (1999) Interface shear strength of titanium implants with a sandblasted and acid-etched surface: a biomechanical study in the maxilla of miniature pigs. *Journal of Biomedical Materials Research* **45**: 75–83.
- Chiapasco, M., Romeo, E., Casentini, P. & Rimondini, L. (2004) Alveolar distraction osteogenesis vs. Vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: a 1-3-year prospective study on humans. *Clinical Oral Implants Research* **15**: 82–95.
- Chiapasco, M., Zaniboni, M. & Boisco, M. (2006) Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. *Clinical Oral Implants Research* **17**(Suppl. 2): 136–159.
- Cochran, D.L., Buser, D., ten Bruggenkate, C.M., Weingart, D., Taylor, T.M., Bernard, J.P., Peters, F. & Simpson, J.P. (2002) The use of reduced healing times on ITI implants with a sandblasted and acid-etched (SLA) surface: early results from clinical trials on ITI SLA implants. *Clinical Oral Implants Research* **12**: 144–153.
- Cochran, D.L., Nummikoski, P.V., Higginbottom, F.L., Hermann, J.S., Makins, S.R. & Buser, D. (1996) Evaluation of an endosseous titanium implant with a sandblasted and acid-etched surface in the canine mandible: radiographic results. *Clinical Oral Implants Research* **7**: 240–252.
- Cochran, D.L., Schenk, R.K., Lussi, A., Higginbottom, F.L. & Buser, D. (1998) Bone response to unloaded and loaded titanium implants with a sandblasted and acid-etched surface: a histometric study in the canine mandible. *Journal of Biomedical Materials Research* **40**: 1–11.
- Ding, X., Liao, S.H., Zhu, X.H., Zhang, X.H. & Zhang, L. (2009) Effect of diameter and length on stress distribution of the alveolar crest around immediate loading implants. *Clinical Oral Implants Research* **11**: 279–287.
- Felice, P., Pellegrino, G., Checchi, L., Pistilli, R. & Esposito, M. (2010) Vertical augmentation with interpositional blocks of anorganic bovine bone vs. 7-mm-long implants in posterior mandibles: 1-year results of a randomized clinical trial. *Clinical Oral Implants Research* **21**: 1394–1403.
- Fontana, F., Santoro, F., Maiorana, C., Iezzi, G., Piattelli, A. & Simion, M. (2008) Clinical and histologic evaluation of allogenic bone matrix versus autogenous bone chips associated with titanium-reinforced e-ptfe membrane for vertical ridge augmentation: a prospective pilot study. *The International Journal of Oral & Maxillofacial Implants* **23**: 1003–1012.
- Glantz, P.O. & Nilner, K. (1998) Biomechanical aspects of prosthetic implant-borne reconstructions. *Periodontology* **17**: 119–124.
- Griffin, T.J. & Cheung, W.S. (2004) The use of short implants in posterior areas with reduced bone height: a retrospective investigation. *Journal of Prosthetic Dentistry* **92**: 139–144.
- Jung, R.E., Pjetursson, B.E., Glauser, R., Zembic, A., Zwahlen, M. & Lang, N.P. (2008) A systematic review of the 5-year survival and complication rates of implant-supported single crowns. *Clinical Oral Implants Research* **19**: 119–130.
- Lai, H.C., Zhuang, L.F., Lv, X.F., Zhang, Z.Y., Zhang, Y.X. & Zhang, Z.Y. (2010) Osteotome sinus floor elevation with or without grafting: a preliminary clinical trial. *Clinical Oral Implants Research* **21**: 520–526.
- Lekholm, U. & Zarb, G.A. (1985) Patient selection and preparation. In: Branemark, P.I., Zarb, G.A. & Albrektsson, T., eds. *Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry*, 199–208. Chicago: Quintessence.
- Mericske-Stern, R., Grütter, L., Rösch, R. & Mericske, E. (2001) Clinical evaluation and prosthetic complications of single tooth replacements by non-submerged implants. *Clinical Oral Implants Research* **12**: 309–318.
- Merli, M., Migani, M. & Esposito, M. (2007) Vertical ridge augmentation with autogenous bone grafts: resorbable barriers supported by osteosynthesis plates versus titanium-reinforced barriers. A preliminary report of a blinded, randomized controlled clinical trial. *The International Journal of Oral & Maxillofacial Implants* **22**: 373–382.
- Misch, C.E., Steigenge, J., Barboza, E., Misch-Dietsh, F., Cianciola, L.J. & Kazor, C. (2006) Short dental implants in posterior partial edentulism: a multicenter retrospective 6-years case series study. *Journal of Periodontology* **77**: 1340–1347.
- Mombelli, A. & Lang, N.P. (1998) The diagnosis and treatment of periimplantitis. *Periodontology* **2000** **17**: 63–76.
- Morand, M. & Irinakis, T. (2007) The challenge of implant therapy in the posterior maxilla: providing a rationale for the use of short implants. *The Journal of Oral Implantology* **33**: 257–266.
- Nedir, R., Bischof, M., Briaux, J.M., Beyer, S., Szmukler-Moncler, S. & Bernard, J.P. (2004) A 7-year life table analysis from a prospective study on ITI implants with special emphasis on the use of short implants. Results from a private practice. *Clinical Oral Implants Research* **15**: 150–157.
- das Neves, F.D., Fones, D., Bernardes, S.R., do Prado, C.J. & Neto, A.J. (2006) Short implants- an analysis of longitudinal studies. *The International Journal of Oral & Maxillofacial Implants* **21**: 86–93.
- Nissan, J., Ghelfan, O., Gross, M. & Chaushu, G. (2010) Analysis of load transfer and stress distribution by splinted and unsplinted implant-supported fixed cemented restorations. *Journal of Oral Rehabilitation* **37**: 658–662.
- Pierrisnard, L., Renouard, F., Renault, P. & Barquinis, M. (2003) Influence of implant length and bicortical anchorage on implant stress distribution. *Clinical Oral Implants Research* **5**: 254–262.
- Pjetursson, B.E., Tan, K., Lang, N.P., Bragger, U., Egger, M. & Zwahlen, M. (2004a) A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. *Clinical Oral Implants Research* **15**: 625–642.
- Pjetursson, B.E., Tan, K., Lang, N.P., Bragger, U., Egger, M. & Zwahlen, M. (2004b) A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. *Clinical Oral Implants Research* **15**: 667–676.
- Pjetursson, B.E., Tan, W.C., Zwahlen, M. & Lang, N.P. (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. Part I: lateral approach. *Journal of Clinical Periodontology* **35**(Suppl): 216–240.
- Rangert, B.R., Sullivan, R.M. & Jemt, T.M. (1997) Load factor control for implants in the posterior partially edentulous segment. *International Journal of Oral & Maxillofacial Implants* **12**: 360–370.
- Renouard, F. & Nisand, D. (2006) Impact of implant length and diameter on survival rates. *Clinical Oral Implants Research* **17**(Suppl. 2): 35–51.
- Rocchietta, I., Fontana, F. & Simion, M. (2008) Clinical outcomes of vertical bone augmentation to enable dental implant placement: a systematic review. *Journal of Clinical Periodontology* **35**: 230–242.
- Rocuzzo, M., Bunino, M., Prioglio, F. & Bianchi, S. D. (2001) Early loading of sandblasted and acid-etched (SLA) implants: a prospective split-mouth comparative study. One year results. *Clinical Oral Implants Research* **12**: 572–578.
- Rocuzzo, M. & Wilson, T.G. (2002) A prospective study evaluating a protocol for 6 weeks loading of SLA implants in the posterior maxilla. *Clinical Oral Implants Research* **12**: 502–507.
- Romeo, E., Chiapasco, M., Ghisolfi, M. & Vogel, G. (2002) Long-term clinical effectiveness of oral implants in the treatment of partial edentulism. Seven-year life table analysis of a prospective study with ITI dental implants system used for single-tooth restorations. *Clinical Oral Implants Research* **13**: 133–143.
- Romeo, E., Lops, D., Margutti, E., Ghisolfi, M., Chiapasco, M. & Vogel, G. (2004) Long-term survival and success of oral implants in the treatment of full and partial arches: a 7-year prospective study with the ITI Dental Implant System. *The International Journal of Oral & Maxillofacial Implants* **19**: 247–259.
- Rossi, F., Ricci, E., Marchetti, C., Lang, N.P. & Botticelli, D. (2010) Early loading of single crowns supported by 6-mm-long implants with a moderately rough surface: a prospective 2-year follow-up cohort study. *Clinical Oral Implants Research* **21**: 937–943.
- Solnit, G.S. & Schneider, R.L. (1998) An alternative to splinting multiple implants: use of the ITI system. *Journal of Prosthodontics* **7**: 114–119.
- Stellingsma, K., Bouma, J., Stegenga, B., Meijer, H.J. & Raghoobar, G.M. (2003) Satisfaction and psychosocial aspects of patients with an extremely resorbed mandible treated with implant-retained overdentures. A prospective, comparative study. *Clinical Oral Implants Research* **14**: 166–172.
- Sticker, A., Voss, P.J., Guwald, R., Schramm, A. & Schmelzeisen, R. (2003) Maxillary sinus floor augmentation with autogenous bone grafts to enable

- placement of SLA surfaced implants: preliminary results after 15–40 months. *Clinical Oral Implants Research* **14**: 207–212.
- Sul, Y.T., Jönsson, J., Yoon, G.S. & Johansson, C. (2009) Resonance frequency measurements *in vivo* and related surface properties of magnesium-incorporated, micropatterned and magnesium-incorporated TiUnites, Osseotites, SLA and TiOblast implants. *Clinical Oral Implants Research* **20**: 1146–1155.
- Tan, W.C., Lang, N.P., Zwahlen, M. & Pjetursson, B.E. (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. Part II: transalveolar technique. *Journal of Clinical Periodontology* **35**(Suppl): 241–254.
- Telleman, G., Raghoobar, G.M., Vissink, A., den Hartog, L., Huddleston Slater, J.J.R. & Meijer, H.J. A. (2011) A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient. *Journal of Clinical Periodontology* **38**: 667–676.
- Testori, T., Wiseman, L., Woolfe, S. & Porter, S.S. (2001) A prospective multicenter clinical study of the Osseotite implant: four-year interim report. *The International Journal of Oral & Maxillofacial Implants* **16**: 193–200.
- Tonetti, M.S. & Hämmerle, C.H.F. and on behalf of the European Workshop on Periodontology Group C (2008) Advances in bone augmentation to enable dental implant placement: consensus Report of the Sixth European Workshop on Periodontology. *Journal of Clinical Periodontology* **35**: 168–172.
- Weng, D., Jacobson, Z., Tarnow, D., Hürzeler, M.B., Faehn, O., Sanavi, F., Barkvoll, P. & Stach, R.M. (2003) A prospective multicenter clinical trial of 3i machined-surface implants: results after 6 years of follow-up. *The International Journal of Oral & Maxillofacial Implants* **18**: 417–423.
- Winkler, S., Morris, H.F. & Ochi, S. (2000) Implant survival to 36 months as related to length and diameter. *Annals of Periodontology* **5**: 22–31.