

Yun-Chi Wang*
Joseph Y. K. Kan
Kitichai Rungcharassaeng
Phillip Roe
Jaime L. Lozada

Marginal bone response of implants with platform switching and non-platform switching abutments in posterior healed sites: a 1-year prospective study

Authors' affiliations:

Yun-Chi Wang, Jaime L. Lozada, Advanced Education in Implant Dentistry, Loma Linda University, School of Dentistry, Loma Linda, CA, USA

Joseph Y. K. Kan, Phillip Roe, Department of Restorative Dentistry, Loma Linda University, School of Dentistry, Loma Linda, CA, USA
Kitichai Rungcharassaeng, Department of Orthodontics and Dentofacial Orthopedics, Loma Linda University, School of Dentistry, Loma Linda, CA, USA

Corresponding author:

Joseph Y. K. Kan, DDS, MS
Center for Implant Dentistry
Loma Linda University School of Dentistry
Loma Linda, California 92350
USA
Tel.: (011) 1-909-558 4980
Fax: (011) 1-909-558-4803
e-mail: jkan@llu.edu

Key words: bone change, conical connection, implant, partial edentulism, platform switching, posterior healed site, subcrestal placement

Abstract

Objectives: This 1-year prospective study evaluated the implant success rate and marginal bone response of non-submerged implants with platform and non-platform switching abutments in posterior healed sites.

Material and methods: Nineteen patients (9 male, 10 female) with posterior partially edentulous spaces, between the ages of 23 and 76 (mean = 55.4 years), were included in this study. A total of 30 implants (15 implants restored with platform switching [PS] abutments [control] and 15 implants restored with non-platform switching [NPS] abutments [test]) were assigned between two groups using a randomization procedure. The definitive abutments with conical connections were placed at the time of surgery, and the definitive restorations were placed at 3 months. All patients were evaluated clinically and radiographically using standardized radiographs at time of implant placement (0), 3, 6 and 12 months after implant placement. Data were analyzed using Friedman test with post hoc pairwise comparisons, Mann-Whitney U-test, and Pearson's chi-square test at the significance level of $\alpha = 0.05$.

Results: At 12 months, all 30 implants remained osseointegrated corresponding to a 100% success rate. The overall mean marginal bone level change at 12 months was -0.04 ± 0.08 mm for PS group and -0.19 ± 0.16 mm for NPS group. Statistically significant difference in the marginal bone level change was observed between groups at 0 to 12 months and 3 to 12 months ($P < 0.05$).

Conclusions: This 1-year randomized control study suggests that when a conical implant-abutment connection is present, similar peri-implant tissue responses can be achieved with platform switching and non-platform switching abutments.

Peri-implant marginal bone change around dental implants is one of the frequently used criteria when evaluating implant success (Albrektsson et al. 1986; Smith & Zarb 1989). Marginal bone change around implants can be related to multiple factors (Ericsson et al. 1995; Abrahamsson et al. 1996; Berglundh & Lindhe 1996; Hermann et al. 2000; Oh et al. 2002; Brogгинi et al. 2003). It has been postulated that the inflammatory cell infiltrate around the microgap at the implant-abutment junction (IAJ) causes bone remodeling, forming a connective tissue barrier, which in turn protects the underlying bone (Ericsson et al. 1995; Brogгинi et al. 2003). Lazzara and Porter (2006) reported the concept of platform switching (PS), in which the diameter of the implant platform was larger than the

corresponding abutment. It had been suggested that PS might keep the bone close to the implant platform minimizing peri-implant marginal bone loss (Lazzara & Porter 2006). The inward reposition of the IAJ may not only provide a horizontal space for the biological width, but also shift the microgap/inflammation away from the bone (Lazzara & Porter 2006). Since then, studies have shown positive but inconclusive data on the effect of PS implant-abutment connections on marginal bone change (Cappiello et al. 2008; Becker et al. 2009; Vigolo & Givani 2009; Cannullo et al. 2010; Linkevicius et al. 2010; Chung et al. 2011; Enkling et al. 2011a,b).

The purpose of this 1-year randomized control study was to compare the marginal bone level changes around non-submerged

*This research was in partial fulfillment of a Master of Science in Dentistry degree for the primary author.

Date:

Accepted 29 October 2013

To cite this article:

Wang Y-C, Kan JYK, Rungcharassaeng K, Roe P, Lozada JL. Marginal bone response of implants with platform switching and non-platform switching abutments in posterior healed sites: a 1-year prospective study. *Clin. Oral Impl. Res.* 00, 2014, 1-8
doi: 10.1111/clr.12312

implants with PS and non-platform switching (NPS) abutments in posterior healed sites.

Materials and methods

Patient selection

This study was approved by the Institutional Review Board of Loma Linda University and was conducted in the Center for Implant Dentistry, Loma Linda University School of Dentistry. To be included in this study, the patients must: (i) be at least 18 years of age with good oral hygiene, (ii) possess one or more missing teeth in the maxillary or mandibular posterior region (excluding third molars), (iii) have adequate bone thickness to accommodate a 4.5 mm diameter implant, (iv) have the presence of opposing dentition. Those patients with: (i) implant insertion torque value of <35 Ncm, (ii) a history of alcohol or drug dependency, or any medical, physical, or psychological factor that might affect the surgical or prosthodontic treatment and required follow-up examinations, (iii) history of bruxism, (iv) history of smoking, and/or (v) head and neck radiation treatment were excluded.

A coin toss was utilized to randomize the abutment (PS or NPS) placed in the patient. If patients were receiving more than one implant, the randomization was performed in such a way that the difference in the number of abutments of each group in the patient was not more than one. For example, if a patient was receiving 5 implants, 2 abutments would belong to one group and 3 abutments would belong to another group.

Clinical procedures

Following the administration of local anesthetic (2% Lidocaine with 1 : 100,000 epinephrine [Dentsply, York, PA, USA]), a full-thickness flap was reflected, and alveoplasty was performed to level the alveolar crest prior to implant placement. The implants used in this study were 4.5 mm in diameter, threaded with SLA surface, and an internal conical connection (Superline™, DentiumUSA, Cypress, CA, USA) (Fig. 1). The implants were placed 0.5 mm subcrestally with a minimum insertion torque of 35 Ncm (Fig. 2). Resonance frequency analysis (RFA) was used to evaluate implant stability. Multiple unit abutments (either PS or NPS) were randomly selected and placed at time of surgery. The PS multiple unit abutment (Screw Abutment; Dentium Co., Ltd., Gangnam-gu, Seoul, Korea) with a horizontal mismatch of 0.6 mm was used as the control group

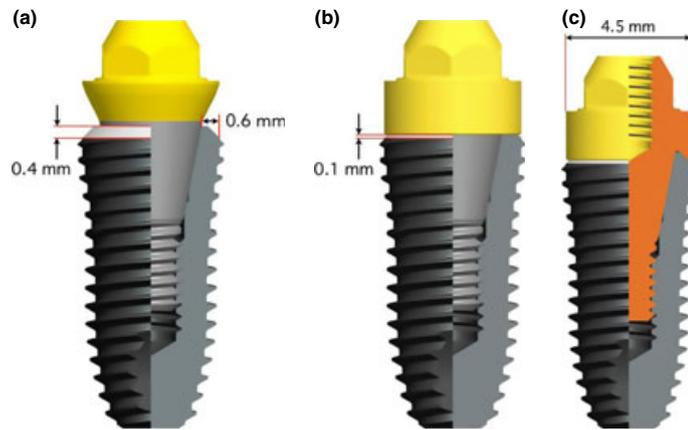


Fig. 1. Schematic drawings illustrating the implant–abutment connections. The distance between the IAJ and the RL was 0.4 mm for the PS multiple unit abutment (a) and 0.1 mm for the NPS multiple unit abutment (b and c). [Correction added on 23 January 2014, after first online publication: Figures 1(a) and (b) were published in the wrong order and have been transposed to the correct order]



Fig. 2. The implant was placed 0.5 mm subcrestally following alveoplasty and osteotomy.



Fig. 4. Placement of the screw-retained all ceramic crown 3 months after implant placement.



Fig. 3. Connection of the multiple unit abutment immediately after implant placement.

(Fig. 1), while the NPS multiple unit abutment (Dentium Co., Ltd.) was used as the test group (Fig. 1). The abutments were torqued to 25 Ncm (Fig. 3) and plastic healing covers (Comfort Cap, Dentium Co., Ltd.) placed. Flaps were approximated to allow for non-submerged healing using an absorbable polyglactin sutures (5-0 Vicryl Plus Antibacterial suture [Ethicon; Johnson & Johnson, Somerville, NJ, USA]).

Antibiotics (Amoxicillin 500 mg [Ranbaxy Laboratories Ltd., New Delhi, India]) and analgesics (Ibuprofen 800 mg [BASF Corporation, Shreveport, LA, USA]) were prescribed

post-operatively. The patients were instructed to rinse with a 0.12% chlorhexidine gluconate solution (Peridex, Zila Pharmaceuticals, Inc., Phoenix, AZ, USA) twice daily and refrain from functioning over the surgical site for the initial 3 weeks. A soft diet was recommended throughout the remaining healing period (3 months).

At 2 months, a definitive abutment level impression was made (Aquasil Monophase; Dentsply, Milford, DE, USA). At 3 months, definitive screw-retained all ceramic crown (Dentium Co., Ltd.) was connected to the multiple unit abutment with a torque of 10 Ncm (manufacturer's recommendation) (Fig. 4).

Data collection

All examinations and data collections were performed by one examiner (Y.W.). Evaluations were made at the time of implant surgery (0) and at 3, 6, and 12 months following implant placement. The following parameters were evaluated at each follow-up appointment when applicable: implant success (Smith & Zarb 1989), marginal bone level (MBL) and marginal bone level change

(MBLC), RFA (Sennerby & Meredith 2008; Zix et al. 2008), modified Plaque Index (mPI) (Mombelli et al. 1987), and surgical/prosthetic complications.

Implant success

The implant success rates were evaluated according to the criteria proposed by Smith and Zarb (1989) where applicable.

Marginal bone level and marginal bone level change

The MBLs were measured on the mesial and distal aspects of each implant using sequential standardized periapical radiographs and the long-cone paralleling technique (Strid 1985). A customized occlusal jig was made using a polyvinyl siloxane bite registration material (Exabite; GC America Inc, Alsip, IL, USA) to standardize the angulation and position of the film. The junction between the micro-roughened surface and the machined surface was used as the reference line (RL) (Fig. 5). The distance between the RL and the most coronal bone–implant contact was measured. The value zero was designated when the MBL was at the same level or coronal to the RL and negative when the bone–implant contact was apical to the RL. The average value of the mesial and distal measurements was used to represent the MBL for each implant. The MBLs were measured at 0, 3, 6 and 12 months after implant placement (Figs 6 and 7). The MBLs and MBLCs were calculated and compared within group and between groups at designated time intervals. The intraexaminer reliability of the measurements was determined by using double

assessments of MBL taken 2 months apart by one examiner and expressed as the intraclass correlation coefficient (ICC).

Resonance frequency analysis

The RFA instrument (Osstell ISQ, Gothenburg, Sweden) was used to evaluate implant stability immediately after implant placement (Sennerby & Meredith 2008; Zix et al. 2008).

Modified plaque index

Presence or absence of plaque was assessed at 6 sites (mesiolabial, labial, distolabial, mesiolingual, lingual, and distolingual) around the abutment or the definitive restoration (Mombelli et al. 1987).

Surgical and prosthetic complications

Surgical complications were recorded and included but not limited to soft tissue problems, infection, or modifications of manufacturer’s recommendations for implant placement. Prosthetic complications were documented, but were not limited to screw loosening, and/or repair of definitive restoration.

Data analysis

The Friedman test with post hoc pairwise comparisons was used to compare the MBLs

and MBLCs within group, while the Mann–Whitney U-test was used to assess the MBLs and MBLCs between groups. Pearson chi-square test was performed to evaluate the intragroup and intergroup differences in mPI. The level of significance was set at $\alpha = 0.05$.

Results

A total of 30 implants (15 with PS abutments and 15 with NPS abutments) randomly assigned to nine male and 10 female patients between ages of 23 and 76 (mean age 55.4 years) were included in this study (Table 1). All implants possessed a diameter of 4.5 mm, with varied length (8, 10 and 12 mm). For the PS group, 5 implants were placed in the posterior maxilla and 10 implants in the posterior mandible, while for the NPS group, 3 implants were placed in the posterior maxilla and 12 implants in the posterior mandible. After one year, all implants (30/30) were stable and none had lost osseointegration, which corresponded to an overall implant success rate of 100%.

The ICC for marginal bone level measurements was 0.99, indicating that the measurements were reliable and reproducible. At baseline, the MBLs were at or coronal to the RL for all mesial and distal sites for the PS

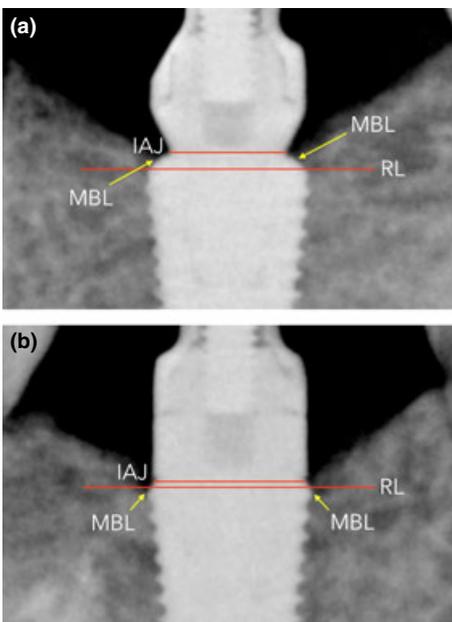


Fig. 5. Reference line (RL) used to determine marginal bone level for the PS group (a) and the NPS group (b).

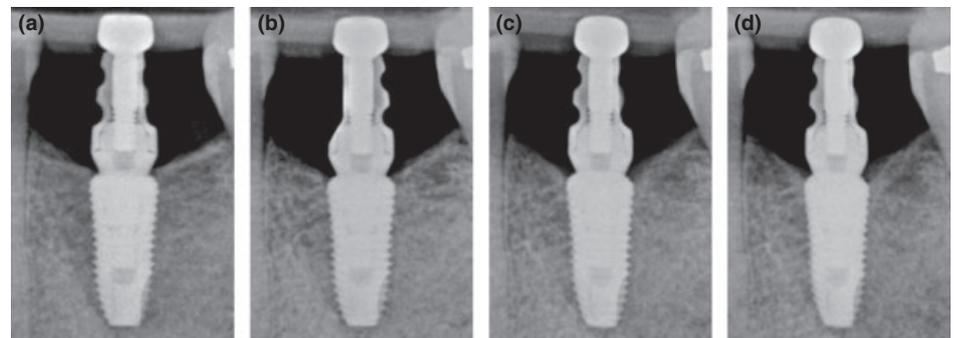


Fig. 6. Radiographs taken at the day of implant placement (0) (a), 3 months (b), 6 months (c), and 12 months (d) for the PS group.

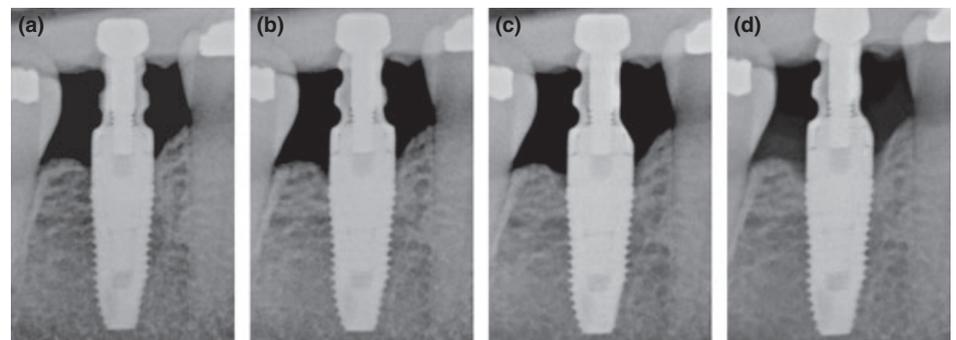


Fig. 7. Radiographs taken at the day of implant placement (0) (a), 3 months (b), 6 months (c), and 12 months (d) for the NPS group.

Table 1. Patient distribution, locations, and implant dimensions

Patient no.	Gender	Tooth no.	Platform type	Implant dimensions (mm)
1	M	13	PS	4.5 × 12
		14	NPS	4.5 × 12
		19	PS	4.5 × 12
		20	NPS	4.5 × 12
		28	PS	4.5 × 12
		29	NPS	4.5 × 12
		30	PS	4.5 × 12
2	M	18	PS	4.5 × 12
3	F	30	NPS	4.5 × 10
4	M	30	NPS	4.5 × 8
5	M	19	PS	4.5 × 8
6	F	14	PS	4.5 × 10
7	F	4	NPS	4.5 × 10
		13	PS	4.5 × 10
8	F	29	NPS	4.5 × 8
		21	PS	4.5 × 12
9	M	19	NPS	4.5 × 10
		19	NPS	4.5 × 10
10	F	19	NPS	4.5 × 10
		29	NPS	4.5 × 12
11	M	30	PS	4.5 × 12
		19	PS	4.5 × 10
12	F	19	NPS	4.5 × 12
13	M	19	NPS	4.5 × 12
14	F	30	NPS	4.5 × 12
15	F	3	PS	4.5 × 12
		2	NPS	4.5 × 12
16	M	14	PS	4.5 × 10
17	F	30	NPS	4.5 × 10
18	F	18	PS	4.5 × 10
19	M	19	PS	4.5 × 10
		30	NPS	4.5 × 12

(30/30) and NPS (30/30) group, while at 12-months, the MBLs of only 20/30 for the PS group and 15/30 for the NPS group were still found at or coronal to the RL. For statistical analysis, one implant per patient was randomly selected accounting for eight independent implants in the PS group and 11 independent implants in the NPS group (Tables 2–5). The overall MBLs at different

time intervals and corresponding MBLCs for the two groups are listed in Tables 2–4. For the PS group, changes in MBLs were not statistically significant between all time periods ($P > 0.05$; Table 2). For the NPS group, significant differences were noted between all time points ($P < 0.05$) except between 0 and 3 months ($P = 0.066$), and 6 and 12 months ($P = 0.483$) (Table 3). When comparing MBLC

Table 2. Comparison of the overall marginal bone level (MBL) and marginal bone level change (MBLC) at different time intervals for the PS group using Friedman test with post hoc pairwise comparisons at $\alpha = 0.05$

		Time interval (months)		
		3	6	12
	Mean ± SD MBL (mm)	-0.08 ± 0.19	-0.10 ± 0.17	-0.04 ± 0.08
Time interval (months)				
0	0	[-0.08 ± 0.19] {0.00} $P = 0.180$	[-0.10 ± 0.17] {0.00} $P = 0.109$	[-0.04 ± 0.08] {0.00} $P = 0.180$
3	-0.08 ± 0.19		[-0.03 ± 0.08] {0.00} $P = 0.285$	[0.04 ± 0.22] {0.00} $P = 1.0$
6	-0.10 ± 0.17			[0.07 ± 0.17] {0.00} $P = 0.109$
12	-0.04 ± 0.08			

$N = 8$.
[] denotes mean ± SD of marginal bone level changes between the time intervals.
{ } denotes median of marginal bone level changes between the time intervals.

between PS and NPS groups, statistically significant differences were noted at 0–12 months ($P = 0.041$) and 3–12 months ($P = 0.026$) (Table 4).

The mean ISQ value at the time of implant placement was 70 (Range = 57–82). The mPI scores of 0 and 1 were consistently observed throughout the study (Table 5). No statistically significant difference was found within the group or between the two groups at the three time intervals ($P > 0.05$; Table 5).

Insertion torque of <35 Ncm was observed with 4 implants during placement, and they were not included in the study. Damage to the internal hex connection of one implant was observed during placement. The implant was removed and replaced uneventfully. The only prosthetic complication observed throughout the study was definitive prosthetic screw loosening. Prosthetic screw loosening was observed on 2 implants in two patients at 6-month follow-up and on 7 implants in four patients at 12-month follow-up. Each incidence of screw loosening was associated with a different implant for a total of 9 implants. No recurrence of prosthetic screw loosening on the same implant was noted in this study. Higher incidence of screw loosening was noted in the molar area (78% [7/9]) than the premolar area (22% [2/9]). All loose prosthetic screws were replaced and torqued to 10 Ncm (manufacturer’s recommendation).

Discussion

In this study, all implants remained osseointegration at 1 year, corresponding to a 100% (30/30) implant success rate. These findings are comparable to studies with various implant systems placed at healed sites with either PS (Norton 2001; Nentwig 2004; Mangano et al. 2010; Rismanchian et al. 2011) [95.6–100%] or NPS (Naert et al. 2000; Polizzi et al. 2000; Testori et al. 2001; Griffin & Cheung 2004) [92–100%] abutments. The success rate of implants with SLA surface used in this study is also comparable to that reported for implants with similar surface (98.8–100%) (Bornstein et al. 2007; Cochran et al. 2011; Karabuda et al. 2011).

In this study, although the difference in MBLC at 12 months between the PS group (-0.04 mm) and the NPS group (-0.19 mm) was statistically significant ($P = 0.041$; Table 4), it was not clinically significant. It is interesting to note that the MBLC reported in studies using implants with PS connection (ranged from -0.11 to -1.1 mm) (Mangano

Table 3. Comparison of the overall marginal bone level (MBL) and marginal bone level change (MBLC) at different time intervals for the NPS group using Friedman test with post hoc pairwise comparisons at $\alpha = 0.05$

		Time interval (months)		
		3	6	12
Mean \pm SD MBL (mm)		-0.05 \pm 0.07	-0.17 \pm 0.19	-0.19 \pm 0.16
Time interval (months)				
0	0	[-0.05 \pm 0.07] {0.00} <i>P</i> = 0.066	[-0.17 \pm 0.19] {-0.19} <i>P</i> = 0.028*	[-0.19 \pm 0.16] {-0.22} <i>P</i> = 0.012*
3	-0.05 \pm 0.07		[-0.13 \pm 0.17] {-0.12} <i>P</i> = 0.027*	[-0.14 \pm 0.13] {-0.18} <i>P</i> = 0.012*
6	-0.17 \pm 0.19			[-0.01 \pm 0.17] {-0.04} <i>P</i> = 0.483
12	-0.19 \pm 0.16			

N = 11.
*Statistically significant difference.
[] denotes mean \pm SD of marginal bone level changes between the time intervals.
{ } denotes median of marginal bone level changes between the time intervals.

Table 4. Comparison of marginal bone level changes (MBLCs) at different time intervals between the PS and the NPS groups (0–3, 0–6, 0–12, 3–6, 3–12, 6–12 months) using Mann–Whitney U-test at $\alpha = 0.05$

Time Interval (months)	Mean \pm SD of MBLC (mm)		Mean difference	Standard error difference	95% CI		<i>P</i>
	PS (<i>N</i> = 8)	NPS (<i>N</i> = 11)			Lower	Upper	
0–3	-0.08 \pm 0.19 [0.00]	-0.05 \pm 0.07 [0.00]	-0.03	0.07	-0.19	0.13	0.717
0–6	-0.10 \pm 0.17 [0.00]	-0.17 \pm 0.19 [-0.19]	0.07	0.08	-0.11	0.25	0.351
0–12	-0.04 \pm 0.08 [0.00]	-0.19 \pm 0.16 [-0.22]	0.15	0.06	0.03	0.27	0.041*
3–6	-0.03 \pm 0.08 [0.00]	-0.13 \pm 0.17 [-0.12]	0.10	0.06	-0.02	0.22	0.129
3–12	0.04 \pm 0.22 [0.00]	-0.14 \pm 0.13 [-0.18]	0.18	0.09	-0.01	0.37	0.026*
6–12	0.07 \pm 0.17 [0.00]	-0.01 \pm 0.17 [-0.04]	0.08	0.08	-0.09	0.25	0.062

*Statistically significant difference.
[] denotes median of marginal bone level changes between the time intervals.

Table 5. Distribution and comparison of mPI scores at different time intervals using Pearson chi-square test at $\alpha = 0.05$

	PS (<i>N</i> = 8)				NPS (<i>N</i> = 11)				<i>P</i> ¹
	0	1	2	3	0	1	2	3	
3 months	6	2	0	0	9	2	0	0	1.0
6 months	8	0	0	0	8	3	0	0	0.23
12 months	7	1	0	0	8	3	0	0	0.60
<i>P</i> ²	0.75				1.0				

¹*P*, comparison between groups; ²*P*, comparison within group.

et al. 2010; Enkling et al. 2011a,b; Norton 2006; Donovan et al. 2010; Canullo et al. 2012) was much less than those reported in studies using implants with the NPS connection (ranged from -0.7 to -1.5 mm) (Polizzi et al. 2000; Turkyilmaz et al. 2007; Schincaglia et al. 2008; Annibaldi et al. 2011). Studies investigating the PS implant–abutment

interface have demonstrated that the greater the horizontal mismatch, the less marginal bone level changes were observed (Baffone et al. 2011, 2012). However, in this study, the similar MBLCs observed in the two groups may be in part attributed to the conical connection being used for both the PS and the NPS groups. Microbial leakage

between implants and abutments has been identified as a causative factor for chronic inflammatory infiltration of the peri-implant tissues and subsequent bone loss (Quirynen et al. 1994; Steinebrunner et al. 2005). Although microgaps have been noted at the implant prosthetic platform (Jansen et al. 1997; Orsini et al. 2000; Tsuge et al. 2008), implants with an internal conical connections may provide a more superior seal (Jansen et al. 1997; Merz et al. 2000; Norton 2000; Hansson 2003), allowing less bacterial leakage (Tesmer et al. 2009; Assenza et al. 2012) and less bone loss (Bilhan et al. 2010).

The greatest amount of MBLC observed in this study was during the first 6 months for both PS and NPS groups (Tables 2 and 3). This is in accordance with studies that have shown most of the MBLCs tend to occur within 3–6 months following one-stage implant procedures (Cochran et al. 2009; Roe et al. 2010), and it had been suggested to be related to the establishment of proper physiological–biological dimension (Hartman & Cochran 2004). In fact, during 6–12 months, the PS groups in this study showed bone gain (Table 2). This can be attributed to one implant, which originally presented with distinct bone loss at 3 months, and resulted in some bone filled at 12 months. Few authors have related the peri-implant bone gain to the stimulating capacity of loaded implants in bone remodeling (Brunski 1999) and to the implant surface (Urdeneta et al. 2011; Valderama et al. 2011).

The RFA has been shown to be effective in evaluating implant stability (Bischof et al. 2004). Study has shown that the RFA can reliably determine the implant stability with an ISQ \geq 47 (Nedir et al. 2004). As for predicting future osseointegration, it has been noted that implants with an ISQ \geq 49 at placement, and loaded after 3 months, showed osseointegration after 1 year of function (Nedir et al. 2004). Others have observed similar finding for successfully osseointegrated implants which had an ISQ of 41–82 at placement using one-stage technique (Guler et al. 2011). In this study, the ISQ of 57–82 recorded during surgery was within the range of aforementioned studies, and all the 30 implants maintained osseointegration after 1 year, suggesting primary stability had been achieved at the time of implant placement.

The relationship between oral hygiene and implant failure has been controversial (Berglundh et al. 1992; van Steenberghe et al. 1993); however, it is generally agreed upon that plaque accumulation can cause an inflammatory response resulting in peri-

implant bone changes (Lindquist et al. 1988). The mPI scores observed throughout the course of this study were either 0 or 1 without significant differences noted between groups, implying that the patients were able to maintain a good level of oral hygiene. Therefore, the negative effect of plaque on the marginal bone levels for this study can be considered negligible.

In this study, a high incidence of prosthetic screw loosening was observed (30%). This may be partially attributed to the small prosthetic screw with a limitation of 10 Ncm maximum torque used to connect the definitive crown to the prefabricated multiple unit abutments. With a similar prosthetic design, Levine et al. (1999) also found high incidences of prosthetic screw loosening (22.2%) for single-tooth replacement. As all of the

definitive crowns in this study were screw-retained, the screw loosening complications were easily resolved.

Conclusions

Platform switching and conical implant-abutment connections have both been contributory to the maintenance of the peri-implant bone. Within the limits of this 1-year prospective clinical study, the following conclusions are offered:

1. Overall cumulative implant success rate observed was 100%.
2. Mean marginal bone level change at 12 months was similar for the PS (-0.04 ± 0.08 mm) and NPS (-0.19 ± 0.16 mm) groups.

3. Evidence from this study suggests that peri-implant marginal bone level change may not be related to the platform switch feature as much as the seal at the implant–abutment interface. Nevertheless, due to the small sample size, the results should be interpreted with cautions, and long-term study with larger sample size is warranted.

Acknowledgements: The authors would like to thank Dentium Co., Ltd., South Korea for partially funding this research and Dr. Jung-Wei Chen for the statistical analysis. The authors have no financial interests in any of the products used in this study.

References

- Abrahamsson, I., Berglundh, T., Wennström, J. & Lindhe, J. (1996) The peri-implant hard and soft tissues at different implant systems. A comparative study in the dog. *Clinical Oral Implants Research* **7**: 212–219.
- Albrektsson, T., Zarb, G., Worthington, P. & Eriksson, A.R. (1986) The long-term efficacy of currently used dental implants: a review and proposed criteria of success. *International Journal of Oral Maxillofacial Implants* **1**: 11–25.
- Annibaldi, S., Bignozzi, I., Iacovazzi, L., La Monica, G. & Cristalli, M.P. (2011) Immediate, early and late implant placement in first-molar sites: a retrospective case series. *International Journal of Oral Maxillofacial Implants* **26**: 1108–1122.
- Assenza, B., Tripodi, D., Scarano, A., Perrotti, V., Piattelli, A., Iezzi, G. & D'Ercole, S. (2012) Bacterial leakage in implants with different implant-abutment connections: an in vitro study. *Journal of Periodontology* **83**: 491–497.
- Baffone, G.M., Botticelli, D., Canullo, L., Scala, A., Beolchini, M. & Lang, N.P. (2012) Effect of mismatching abutments on implants with wider platforms – an experimental study in dogs. *Clinical Oral Implants Research* **23**: 334–339.
- Baffone, G.M., Botticelli, D., Pantani, F., Cardoso, L.C., Schweikert, M.T. & Lang, N.P. (2011) Influence of various implant platform configurations on peri-implant tissue dimensions: an experimental study in dog. *Clinical Oral Implants Research* **22**: 438–444.
- Becker, J., Ferrari, D., Mihatovic, I., Sahn, N., Schaer, A. & Schwarz, F. (2009) Stability of crestal bone level at platform-switched non-submerged titanium implants: a histomorphometrical study in dogs. *Journal of Clinical Periodontology* **36**: 532–539.
- Berglundh, T. & Lindhe, J. (1996) Dimension of the periimplant mucosa. Biological width revisited. *Journal of Clinical Periodontology* **23**: 971–973.
- Berglundh, T., Lindhe, J., Marinello, C., Ericsson, I. & Liljenberg, B. (1992) Soft tissue reaction to de novo plaque formation on implants and teeth. An experimental study in the dog. *Clinical Oral Implants Research* **3**: 1–8.
- Bilhan, H., Kutay, O., Arat, S., Cekici, A. & Cehreli, M.C. (2010) Astra Tech, Brånemark, and ITI implants in the rehabilitation of partial edentulism: two-year results. *Implant Dentistry* **19**: 437–446.
- Bischof, M., Nedir, R., Szmukler-Moncler, S., Bernard, J.P. & Samson, J. (2004) Implant stability measurement of delayed and immediately loaded implants during healing. A clinical resonance-frequency analysis study with sandblasted-and-etched ITI implants. *Clinical Oral Implants Research* **15**: 529–539.
- Bornstein, M.M., Harnisch, H., Lussi, A. & Buser, D. (2007) Clinical performance of wide-body implants with a sandblasted and acid-etched (SLA) surface: results of a 3-year follow-up study in a referral clinic. *International Journal of Oral Maxillofacial Implants* **22**: 631–638.
- Broggini, N., McManus, L.M., Hermann, J.S., Medina, R.U., Oates, T.W., Schenk, R.K., Buser, D., Mellonig, J.T. & Cochran, D.L. (2003) Persistent acute inflammation at the implant-abutment interface. *Journal of Dental Research* **82**: 232–237.
- Brunski, J.B. (1999) In vivo bone response to biomechanical loading at the bone/dental-implant interface. *Advances in Dental Research* **13**: 99–119.
- Canullo, L., Fedele, G.R., Iannello, G. & Jepsen, S. (2010) Platform switching and marginal bone-level alterations: the results of a randomized-controlled trial. *Clinical Oral Implants Research* **21**: 115–121.
- Canullo, L., Iannello, G., Peñarocha, M. & Garcia, B. (2012) Impact of implant diameter on bone level changes around platform switched implants: preliminary results of 18 months follow-up a prospective randomized match-paired controlled trial. *Clinical Oral Implants Research* **23**: 1142–1146.
- Cappiello, M., Luongo, R., Di Iorio, D., Bugea, C., Cocchetto, R. & Celletti, R. (2008) Evaluation of peri-implant bone loss around platform-switched implants. *The International Journal of Periodontics and Restorative Dentistry* **28**: 347–355.
- Chung, S., Rungcharassaeng, K., Kan, J.Y., Roe, P. & Lozada, J.L. (2011) Immediate single tooth replacement with subepithelial connective tissue graft using platform switching implants: a case series. *Journal of Oral Implantology* **37**: 559–569.
- Cochran, D.L., Jackson, J.M., Bernard, J.P., ten Bruggenkate, C.M., Buser, D., Taylor, T.D., Weingart, D., Scholfield, J.D., Jones, A.A. & Oates, T.W., Jr. (2011) A 5-year prospective multicenter study of early loaded titanium implants with a sandblasted and acid-etched surface. *International Journal of Oral Maxillofacial Implants* **26**: 1324–1332.
- Cochran, D.L., Nummikoski, P.V., Schoolfield, J.D., Jones, A.A. & Oates, T.W. (2009) A prospective multicenter 5-year radiographic evaluation of crestal bone levels over time in 596 dental implants placed in 192 patients. *Journal of Periodontology* **80**: 725–733.
- Donovan, R., Fetner, A., Koutouzis, T. & Lundgren, T. (2010) Crestal bone changes around implants with reduced abutment diameter placed non-submerged and at subcrestal positions: a 1-year radiographic evaluation. *Journal of Periodontology* **81**: 428–434.
- Enkling, N., Jöhren, P., Klimberg, T., Mericske-Stern, R., Jervøe-Storm, P.M., Bayer, S., Gülden, N. & Jepsen, S. (2011a) Open or submerged healing of implants with platform switching: a randomized, controlled clinical trial. *Journal of Clinical Periodontology* **38**: 374–384.
- Enkling, N., Jöhren, P., Klimberg, V., Bayer, S., Mericske-Stern, R. & Jepsen, S. (2011b) Effect of

- platform switching on peri-implant bone levels: a randomized clinical trial. *Clinical Oral Implants Research* 22: 1185–1192.
- Ericsson, I., Persson, L.G., Berglundh, T., Marinello, C.P., Lindhe, J. & Klinge, B. (1995) Different types of inflammatory reactions in peri-implant soft tissues. *Journal of Clinical Periodontology* 22: 255–261.
- Griffin, T.J. & Cheung, W.S. (2004) The use of short, wide implants in posterior areas with reduced bone height: a retrospective investigation. *Journal of Prosthetic Dentistry* 92: 139–144.
- Guler, A.U., Sumer, M., Duran, I., Sandikci, E.O. & Telcioglu, N.T. (2011) Resonance frequency analysis of 208 Straumann dental implants during the healing period. *Journal of Oral Implantology* 39: 161–167.
- Hansson, S. (2003) A conical implant-abutment interface at the level of the marginal bone improves the distribution of the stresses in the supporting bone. An axisymmetric finite element analysis. *Clinical Oral Implants Research* 14: 286–293.
- Hartman, G.A. & Cochran, D.L. (2004) Initial implant position determines the magnitude of crestal bone remodeling. *Journal of Periodontology* 75: 572–577.
- Hermann, J.S., Buser, D., Schenk, R.K. & Cochran, D.L. (2000) Crestal bone changes around titanium implants. A histometric evaluation of unloaded non-submerged and submerged implants in the canine mandible. *Journal of Periodontology* 71: 1412–1424.
- Jansen, V.K., Conrads, G. & Richter, E.J. (1997) Microbial leakage and marginal fit of the implant-abutment interface. *International Journal of Oral Maxillofacial Implants* 12: 527–540.
- Karabuda, Z.C., Abdel-Haq, J. & Arisan, V. (2011) Stability, marginal bones loss and survival of standard and modified sand-blasted, acid-etched implants in bilateral edentulous spaces: a prospective 15-month evaluation. *Clinical Oral Implants Research* 22: 840–849.
- Lazzara, R.J. & Porter, S.S. (2006) Platform switching: a new concept in implant dentistry for controlling postrestorative crestal bone levels. *The International Journal of Periodontics and Restorative Dentistry* 26: 9–17.
- Levine, R.A., Clem, D.S., III, Wilson, T.G., Jr, Higginbottom, F. & Solnit, G. (1999) Multicenter retrospective analysis of the ITI implant system used for single-tooth replacements: results of loading for 2 or more years. *International Journal of Oral Maxillofacial Implants* 14: 516–520.
- Lindquist, L.W., Rockler, B. & Carlsson, G.E. (1988) Bone resorption around fixtures in edentulous patients treated with mandibular fixed tissue-integrated prostheses. *Journal of Prosthetic Dentistry* 59: 59–63.
- Linkevicius, T., Apse, P., Grybauskas, S. & Puisys, A. (2010) Influence of thin mucosal tissues on crestal bone stability around implants with platform switching: a 1-year pilot study. *Journal of Oral Maxillofacial Surgery* 68: 2272–2277.
- Mangano, C., Mangano, F., Piattelli, A., Iezzi, G., Mangano, A. & La Colla, L. (2010) Prospective clinical evaluation of 307 single-tooth Morse taper-connection implants: a multicenter study. *International Journal of Oral Maxillofacial Implants* 25: 394–400.
- Merz, B.R., Hunenbart, S. & Belser, U.C. (2000) Mechanics of the implant-abutment connection: an 8-degree taper compared to a butt joint connection. *International Journal of Oral Maxillofacial Implants* 15: 519–526.
- Mombelli, A., van Oosten, M.A., Schurch, E., Jr & Lang, N.P. (1987) The microbiota associated with successful or failing osseointegrated titanium implants. *Oral Microbiology and Immunology* 2: 145–151.
- Naert, I., Koutsikakis, G., Duyck, J., Quirynen, M., Jacobs, R. & van Steenberghe, D. (2000) Biologic outcome of single-implant restorations as tooth replacements: a long-term follow-up study. *Clinical Implant Dentistry and Related Research* 2: 209–218.
- Nedir, R., Bischof, M., Szmukler-Moncler, S., Bernard, J.P. & Samson, J. (2004) Predicting osseointegration by means of implant primary stability. *Clinical Oral Implants Research* 15: 520–528.
- Nentwig, G.H. (2004) Ankylos implant system: concept and clinical application. *Journal of Oral Implantology* 30: 171–177.
- Norton, M.R. (2000) In vitro evaluation of the strength of the conical implant-to-abutment joint in two commercially available implant systems. *Journal of Prosthetic Dentistry* 83: 567–571.
- Norton, M.R. (2001) Biologic and mechanical stability of single-tooth implants: 4- to 7-year follow-up. *Clinical Implant Dentistry and Related Research* 3: 214–220.
- Norton, M.R. (2006) Multiple single-tooth implant restorations in the posterior jaws: maintenance of marginal bone levels with reference to the implant-abutment microgap. *International Journal of Oral Maxillofacial Implants* 21: 777–784.
- Oh, T.J., Yoon, J., Misch, C.E. & Wang, H.L. (2002) The causes of early implant bone loss: myth or science? *Journal of Periodontology* 73: 322–333.
- Orsini, G., Fanali, S., Scarano, A., Petrone, G., di Silvestro, S. & Piattelli, A. (2000) Tissue reactions, fluids, and bacterial infiltration in implants retrieved at autopsy: a case report. *International Journal of Oral Maxillofacial Implants* 15: 283–286.
- Polizzi, G., Rangert, B., Lekholm, U., Gualini, F. & Lindström, H. (2000) Brånemark system wide platform implants for single molar replacement: clinical evaluation of prospective and retrospective materials. *Clinical Implant Dentistry and Related Research* 2: 61–69.
- Quirynen, M., Bollen, C.M., Eyssen, H. & van Steenberghe, D. (1994) Microbial penetration along the implant components of the Brånemark system. An in vitro study. *Clinical Oral Implants Research* 5: 239–244.
- Rismanchian, M., Fazel, A., Rakhshan, V. & Eblaghian, G. (2011) One-year clinical and radiographic assessment of fluoride-enhanced implants on immediate non-functional loading in posterior maxilla and mandible: a pilot prospective clinical series study. *Clinical Oral Implants Research* 22: 1440–1445.
- Roe, P., Kan, J.Y., Rungcharassaeng, K., Lozada, J.L., Kleinman, A.S., Goodacre, C.J. & Chen, J.W. (2010) Immediate loading of unsplinted implants in the anterior mandible for overdentures: a case series. *International Journal of Oral Maxillofacial Implants* 25: 1028–1035.
- Schincaglia, G.P., Marzola, R., Giovanni, G.F., Chiara, C.S. & Scotti, R. (2008) Replacement of mandibular molars with single-unit restorations supported by wide-body implants: immediate versus delayed loading. A randomized controlled study. *International Journal of Oral Maxillofacial Implants* 23: 474–480.
- Sennerby, L. & Meredith, N. (2008) () Implant stability measurements using resonance frequency analysis: biological and biomechanical aspects and clinical implications. *Periodontology* 2000 47: 51–66.
- Smith, D.E. & Zarb, G.A. (1989) Criteria for success of osseointegrated endosseous implants. *Journal of Prosthetic Dentistry* 62: 567–572.
- van Steenberghe, D., Klinge, B., Lindén, U., Quirynen, M., Herrmann, I. & Garpland, C. (1993) Periodontal indices around natural and titanium abutments. A longitudinal multicenter study. *Journal of Periodontology* 64: 538–541.
- Steinebrunner, L., Wolfart, S., Bössmann, K. & Kern, M. (2005) In vitro evaluation of bacterial leakage along the implant-abutment interface of different implant systems. *International Journal of Oral Maxillofacial Implants* 20: 875–881.
- Strid, K.G. (1985) Radiographic results. In: Brånemark, P.I., Zarb, G.A. & Albrektsson, T., eds. Tissue integrated prostheses. Osseointegration in Clinical Dentistry. 187–193. Chicago: Quintessence.
- Tesmer, M., Wallet, S., Koutouzis, T. & Lundgren, T. (2009) Bacterial colonization of the dental implant fixture-abutment interface: an in vitro study. *Journal of Periodontology* 80: 1991–1997.
- Testori, T., Wiseman, L., Woolfe, S. & Porter, S.S. (2001) A prospective multicenter clinical study of the Osseotite implant: four-year interim report. *International Journal of Oral Maxillofacial Implants* 16: 193–200.
- Tsuge, T., Hagiwara, Y. & Matsumura, H. (2008) Marginal fit and microgaps of implant-abutment interface with internal anti-rotation configuration. *Dental Materials Journal* 27: 29–34.
- Turkylmaz, I., Avci, M., Kuran, S. & Ozbek, E.N. (2007) A 4-year prospective clinical and radiological study of maxillary dental implants supporting single-tooth crowns using early and delayed loading protocols. *Clinical Implant Dentistry and Related Research* 9: 222–227.
- Urduaneta, R.A., Daher, S., Leary, J., Emanuel, K. & Chuang, S.K. (2011) Factors associated with crestal bone gain on single-tooth locking-taper implants: the effect of nonsteroidal anti-inflammatory drugs. *International Journal of Oral Maxillofacial Implants* 26: 1063–1078.

- Valderrama, P., Bornstein, M.M., Jones, A.A., Wilson, T.G., Higginbottom, F.L. & Cochran, D.L. (2011) Effects of implant design on marginal bone changes around early loaded, chemically modified, sandblasted acid-etched-surfaced implants: a histologic analysis in dogs. *Journal of Periodontology* **82**: 1025–1034.
- Vigolo, P. & Givani, A. (2009) Platform-switched restorations on wide-diameter implants: a 5-year clinical prospective study. *International Journal of Oral Maxillofacial Implants* **24**: 103–109.
- Zix, J., Hug, S., Kessler-Liechti, G. & Mericske-Stern, R. (2008) Measurement of dental implant stability by resonance frequency analysis and damping capacity assessment: comparison of both techniques in a clinical trial. *International Journal of Oral Maxillofacial Implants* **23**: 525–530.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. CONSORT 2010 checklist of information to include when reporting a randomized trial.