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Comparison of peri-implant marginal bone level changes between tapered and straight implant designs: 5-year follow-up results

Han Park [1], **Ik-Sang Moon** [1], **Chooryung Chung** [2], **Su-Jung Shin** [3], **Jong-Ki Huh** [4], **Jeong-Ho Yun** [5,*], **Dong-Won Lee** [1,*]

[1]Department of Periodontology, Gangnam Severance Dental Hospital, Yonsei University College of Dentistry, Seoul, Korea
[2]Department of Orthodontics, Gangnam Severance Dental Hospital, Yonsei University College of Dentistry, Seoul, Korea
[3]Department of Conservative Dentistry, Gangnam Severance Dental Hospital, Yonsei University College of Dentistry, Seoul, Korea
[4]Department of Oral and Maxillofacial Surgery, Gangnam Severance Dental Hospital, Yonsei University College of Dentistry, Seoul, Korea
[5]Department of Periodontology, Institute of Oral Bioscience, Jeonbuk National University College of Dentistry, Jeonju, Korea

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***Correspondence:**
Dong-Won Lee
Department of Periodontology, Gangnam Severance Dental Hospital, Yonsei University College of Dentistry, 211 Unju-ro, Gangnam-gu, Seoul 06273, Korea.
E-mail: periodong@gmail.com
Tel: +82-2-2019-3574
Fax: +82-2-3463-4052

Jeong-Ho Yun
Department of Periodontology, Institute of Oral Bioscience, Jeonbuk National University College of Dentistry, 567 Baekje-daero, Deokjin-gu, Jeonju 54896, Korea.
E-mail: grayheron@hanmail.net
Tel: +82-63-250-2289

ORCID iDs
Han Park
https://orcid.org/0000-0001-6554-6598
Ik-Sang Moon
https://orcid.org/0000-0002-7394-2547
Chooryung Chung
https://orcid.org/0000-0001-9399-7193
Su-Jung Shin
https://orcid.org/0000-0001-5795-3919
Jong-Ki Huh
https://orcid.org/0000-0002-7381-3972
Jeong-Ho Yun
https://orcid.org/0000-0003-3929-4467

ABSTRACT

Purpose: The aim of this study was to compare straight and tapered implant designs in terms of marginal bone loss, the modified plaque index (mPI), and the modified bleeding index (mBI) for 5 years after functional loading.
Methods: Twelve patients were recruited. Two types of implants were placed adjacent to each other: 1 straight implant and 1 tapered implant. Marginal bone loss, mPI, and mBI were measured every year for 5 years after loading.
Results: The straight implants showed 0.2±0.4 mm of marginal bone loss at 5 years after loading, while the tapered implants showed 0.2±0.3 mm of marginal bone loss; this difference was not statistically significant (P=0.833). Our analysis also showed no statistically significant differences in mPI (straight implants: 0.3±0.3 vs. tapered implants: 0.2±0.3; P=0.414) or in mBI (straight implants: 0.3±0.4 vs. tapered implants: 0.2±0.3; P=0.317) at 5 years after prosthesis delivery.
Conclusions: Straight and tapered implants showed no significant differences with respect to marginal bone loss, mPI, and mBI for 5 years after loading.

Keywords: Alveolar bone loss; Bone remodeling; Dental implants

INTRODUCTION

A previous prospective study published by our group compared marginal bone loss between treatments using conical and straight implant neck design at 1 year after loading [1]. The conical implant neck was designed to improve adaptation of the implant to the marginal bone of the extraction socket [2], and it also results in a tapered design of the implant. Tapered implants provide greater primary stability than straight implants [3], leading to

Dong-Won Lee
https://orcid.org/0000-0003-1852-7989

Author Contributions

Conceptualization: Han Park, Jeong-Ho Yun, Dong-Won Lee; Data curation: Han Park, Su-Jung Shin; Formal analysis: Han Park, Jong-Ki Huh; Investigation: Han Park, Jong-Ki Huh, Dong-Won Lee; Methodology: Han Park, Ik-Sang Moon, Dong-Won Lee; Project administration: Jeong-Ho Yun, Dong-Won Lee; Software: Han Park, Chooryung Chung; Supervision: Jeong-Ho Yun, Dong-Won Lee; Validation: Ik-Sang Moon, Su-Jung Shin; Visualization: Han Park, Chooryung Chung; Writing-original draft: Han Park, Jeong-Ho Yun, Dong-Won Lee; Writing-review & editing: Han Park, Ik-Sang Moon, Chooryung Chung, Su-Jung Shin, Jong-Ki Huh, Jeong-Ho Yun, Dong-Won Lee.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

successful implant survival [4]. This finding is also supported by clinical studies regarding the long-term success of tapered implants [5]. Bone-to-implant contact [6] and the pattern of stability changes [7] showed no difference between tapered and straight implants. However, previous clinical studies reported inconsistent results regarding the effects of tapered implants on marginal bone loss. One study showed more marginal bone loss in tapered implants [8], while others showed no difference between tapered and straight implants [1,9]. Therefore, a well-designed prospective study is needed to resolve this controversial issue. The previous prospective study published by our group [1] tried to minimize other factors affecting marginal bone loss. For example, the same line of implants (Astra Tech Osseospeed™, Dentsply Sirona, York, PA, USA), from the same company was used to ensure identical implant abutment connections (Conical Seal Design™, Dentsply Sirona), surface treatment, and thread character. The Astra Tech Osseospeed™ 4.0s implant has a fixture with a straight shape with a 4-mm diameter from the apex to the coronal region, while the 5.0 implant also has a 4-mm diameter at the apex but a 5-mm diameter at the coronal region, which makes it a tapered design. In addition, both the 4.0s and 5.0 implants were placed in adjacent edentulous areas to ensure similar bone quality and connected with a bridge to minimize the difference in the load applied to the implants [10]. All surgical procedures and regular follow-up examinations were performed by a single skilled surgeon to minimize error between surgeons. Regular follow-ups with oral hygiene control and brushing education were done in order to minimize the potential impact of plaque accumulation on marginal bone loss. The results showed no difference between tapered and straight implants at 1 year after loading [1].

However, since systematic reviews showed a good prognosis for the long-term use of implants in both periodontally healthy [11] and periodontally compromised patients [12], a long-term evaluation of this issue is essential. This 5-year follow-up study will provide evidence on this unresolved issue by comparing marginal bone loss between tapered and straight implants during 5 years after functional loading.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of Yonsei University (3-2007-0123 for the 1-year prospective study and 3-2020-0180 for the 5-year retrospective follow-up). The study was also conducted in compliance with the Declaration of Helsinki and the STROBE statement (www.strobe-statement.org).

Patients

Participants were chosen from patients who received periodontal treatment at Gangnam Severance Hospital. The patients were classified based on the 1999 classification standards for periodontal disease upon their first visit [13], and received oral hygiene education, scaling, root planing, and if necessary, extraction or periodontal surgery. The reasons for extraction were mostly due to periodontitis. Some were already edentulous before their first visit. After periodontal treatment and extraction, patients were regularly followed up and administered oral hygiene care. Among these patients, those who needed 2 or more implants in a partially edentulous area and had enough alveolar bone for implant placement were recruited.
The exclusion criteria were as follows: 1) a systemic disease (e.g., uncontrolled diabetes or hypertension), and 2) heavy smoking (>20 cigarettes/day). There were 12 participants, including 6 men and 6 women, with an average age of 64.3 years (range, 53–75 years; **Table 1**).

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Table 1. Participants' characteristics and the position and type of the implants

Subject	Age (yr)	Sex	Implant position	Implant type	Inter-implant distance (mm)
1	73	M	36	S	2.7
			37	T	
2	66	F	24	S	2.7
			25	T	
3	75	M	25	S	3.5
			26	T	
4	59	M	26	S	2.7
			27	T	
5	66	M	25	S	5.2
			26	T	
6	53	F	35	T	6.7
			36	S	
7	64	F	16	S	4.7
			17	T	
8	66	M	36	S	4.0
			37	T	
9	65	F	16	S	3.4
			17	T	
10	64	F	26	S	4.1
			27	T	
11	64	F	15	S	3.0
			16	T	
12	57	M	44	S	3.3
			45	T	

S: Astra Tech Osseospeed™ 4.0s implant, T: Astra Tech Osseospeed™ 5.0 implant.

Implants

In this study, 2 types of Astra Tech Osseospeed™ implants (Dentsply Sirona) were used, both with micro-threads (Micro-thread™, Dentsply Sirona) at their coronal collar, a conical implant-abutment connection (Conical Seal Design™, Dentsply Sirona), and a fluoride-modified TiOblast surface (Osseospeed™, Dentsply Sirona). The Osseospeed™ 4.0s implant (straight type; S) and 5.0 implant (tapered type; T) both had apical diameters of 4 mm, but the T implants had a diameter of 5 mm at the coronal region, while the S implants maintained a diameter of 4 mm straight from the apex to the coronal region (**Figure 1**).

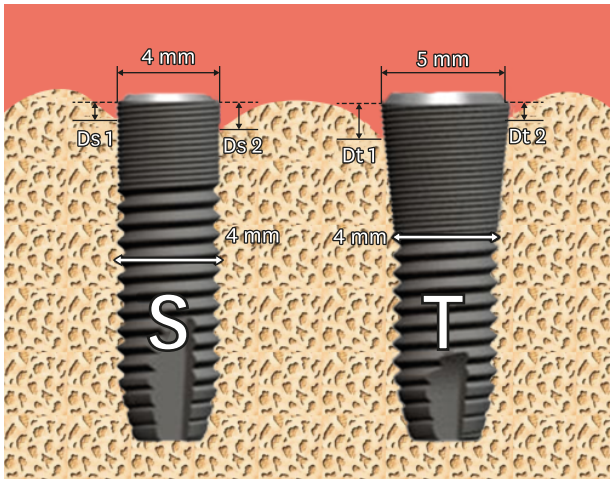

Figure 1. Schematic representation of the site and reference point measurements.
S: Astra Tech Osseospeed™ 4.0s implant, T: Astra Tech Osseospeed™ 5.0 implant, horizontal dotted line: reference point, horizontal solid line: measuring point, Ds1 and Ds2: distance from the reference point to the measuring point at S, Dt1 and Dt2: distance from the reference point to the measuring point at T.

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Treatment procedure

The S and T implants were placed adjacent to each other in the same edentulous area. In most cases, the S implant was installed mesial to the T implant (**Table 1**) to retain at least 1 mm of alveolar bone on both the buccal and lingual sides of the implants.

All implants were placed using the 2-stage submerged surgical technique. The second surgery was performed 3 months after the first surgery for the mandible and 6 months after the first surgery for the maxilla. Three weeks after the second surgery, the cemented type splinted prostheses were delivered. The prostheses were splinted in order to minimize the difference in the load applied to the implants [10].

After the prostheses were delivered, all participants were instructed on personal oral hygiene care and how to use various sizes of interdental brushes for each embrasure of the prostheses [14].

Follow-up parameters

After delivery of the prostheses, the participants visited our clinic every 3-6 months based on their oral hygiene status, and underwent professional plaque control and oral hygiene instruction, which is the basic protocol used for all patients who receive implant treatment in our clinic. Both subjective symptoms (e.g., pain and discomfort) and objective signs (e.g., inflammation, infection, and mobility) were recorded. Every year after delivery of the prostheses, the modified plaque index (mPI) and modified bleeding index (mBI) at 4 points around each implant were measured and the average value was recorded as the representative value [15]. Periapical radiographs were taken every year after delivery of the prostheses [16].

Radiographic examination

Radiographs were taken using protocols previously developed by our group [1,10,14] at 1 day after the first surgery, on the day of the second surgery and prosthesis delivery, and every year after functional loading (**Figure 2**). The parallel cone technique was used with XCP (XCP®, Dentsply Sirona). Before August 2012, periapical radiographs were taken (70 kVp, 10 mA, Yoshida REX 601, Tokyo, Japan) on film (Kodak Insight, film speed F, Rochester,

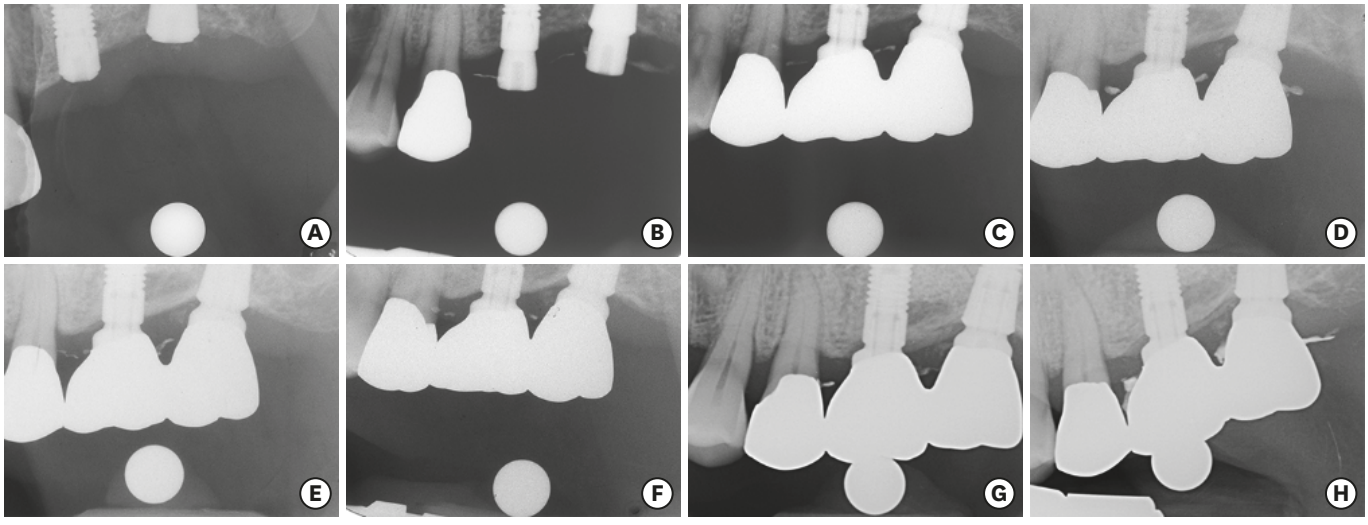

Figure 2. Periapical radiographs of implants. (A) 1 day after the first surgery; (B) the day of second surgery; (C) the day of prostheses delivery; (D) 1 year after functional loading; (E) 2 years after functional loading; (F) 3 years after functional loading; (G) 4 years after functional loading; (H) 5 years after functional loading.

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NY, USA), developed using an automatic processor (Periomat, Dürr Dental, Bietigheim-Bissingen, Germany), and scanned (EPSON GT-12000, EPSON, Nagano, Japan) at 2,400 dpi and 256 gray scale [17]. After August 2012, periapical radiographs were taken (70 kVp, 8 mA, Planmeca Intra, Helsinki, Finland) on image plates (Vistascan Image Plate, Dürr Dental), and scanned using an image plate scanner (Vistascan Perio Plus, Dürr Dental). The scanned files were transferred to a computer (Intel i5-7600 3.5GHz, Santa Clara, CA, USA; Windows 10 Enterprise, Redmond, WA, USA) and the measurements of periapical radiographs were made in a dark room using the same monitor (LS24C45KBSS, Samsung, Seoul, Korea).

Marginal bone level (MBL) change measurements

The reference point for measurements of MBL was set to the borderline of the machined surface and rough surface of the implant. MBL was measured as the vertical distance from the reference point to the contact point of the marginal bone and implant (**Figure 1**). The measurement was made by using the known thread pitch distance or diameter of a metal sphere that was included in the frame while taking periapical radiographs [18]. ImageJ (Version 1.52a, National Institutes of Health, Bethesda, MD, USA) was used for image analysis, and the measured MBL was rounded up to 0.1 mm. The MBL of each implant was measured on the mesial and distal sides, and the average of both values was used as the final reading. MBL on the day of prosthesis delivery was used as the baseline, and the difference between baseline and every year after functional loading was calculated as the extent of marginal bone loss. If the marginal bone showed an increase in bone level, marginal bone loss was considered to be 0. In addition, the nearest distance between the S and T implants was measured and recorded as the inter-implant distance (ID).

Statistical analysis

After collecting the data, the Kolmogorov-Smirnov and Shapiro-Wilk tests were used to analyze the distribution of the data. Since normality was not satisfied, a nonparametric statistical method was used. The Wilcoxon signed rank test was used to compare marginal bone loss, mPI, and mBI between the S and T implants every year after delivery of the prostheses. Marginal bone loss was also compared using nparLD, an R package for the nonparametric analysis of longitudinal data [19] to detect the time of stabilization, the overall difference between the 2 types of implants (S and T), and the interaction between the time and type of implants. If any differences were found to be significant, the Wilcoxon signed rank test was used as a *post hoc* test. To determine possible connections between ID and marginal bone loss, Spearman rank correlations were calculated with the marginal bone loss (Si and Ti; marginal bone loss at inter-implant sides of the S and T implants, respectively) and ID as parameters. In addition, the Mann-Whitney U test was used to compare marginal bone loss between groups (ID ≥3 mm vs. ID <3 mm and maxilla vs. mandible). SPSS version 25 (IBM Corp., Armonk, NY, USA), R version 3.5.3 (R Foundation, Vienna, Austria), and the nparLD package (Noguchi, 2012) were used to process data. Differences were deemed significant if the *P* value was lower than 0.05, and Benjamini-Hochberg (BH) adjustment was applied if multiple comparisons were performed [20].

RESULTS

Clinical examinations

No noticeable side effects were found during the observation period. No patients complained of pain, mobility of the implant, or problems with the prostheses. None of the patients required removal of the implant.

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Evaluation of marginal bone loss

The extent of marginal bone loss recorded every year after delivery of the prostheses and the results of the Wilcoxon signed rank test comparing the values are listed in **Table 2**. There were no significant differences between the S (0.2±0.4 mm) and T (0.2±0.4 mm) implants for 5 years after delivery of the prostheses (P=0.833).

The NparLD package was used to detect MBL differences between time after loading of the prostheses ("time" factor) and the type of implant (S and T, "type" factor), and to find the interaction between time after loading and type of implants ("type:time" factor). The "time" factor (P=0.009) was rejected based on the cutoff of P<0.05, whereas the "type" factor (P=0.147) and "type:time" factors (P=0.340) were not. The Wilcoxon signed rank test was used as a *post hoc* test to analyze which time intervals were significantly different from one another in terms of marginal bone loss (**Table 3**). The test did not reveal statistically significant differences at any time interval in *post hoc* testing with the BH adjustment for multiple comparisons.

In addition, the Mann-Whitney U test comparing marginal bone loss between the maxilla (0.3±0.3 mm) and mandible (0.2±0.4 mm) showed no statistically significant differences (P=1.000) (**Table 4**).

Table 2. MBL changes compared to baseline, mPI, and mBI at 1, 2, 3, 4 and 5 years after delivery of prostheses

Year	Value	Type	Mean	SD	Min.	1st Quartile	Median	3rd Quartile	Max.	Wilcoxon signed rank test (P value)
1	MBL	S	0.1	0.1	0.0	0.0	0.0	0.1	0.3	1.000
		T	0.1	0.2	0.0	0.0	0.0	0.0	0.5	
	mPI	S	0.4	0.4	0.0	0.0	0.5	0.5	1.0	0.734
		T	0.5	0.6	0.0	0.0	0.3	0.9	2.0	
	mBI	S	0.2	0.5	0.0	0.0	0.0	0.0	1.8	0.039
		T	0.3	0.6	0.0	0.0	0.2	0.3	2.0	
2	MBL	S	0.1	0.1	0.0	0.0	0.0	0.2	0.3	0.705
		T	0.1	0.2	0.0	0.0	0.0	0.1	0.5	
	mPI	S	0.3	0.4	0.0	0.0	0.2	0.5	1.3	0.180
		T	0.2	0.3	0.0	0.0	0.0	0.5	1.0	
	mBI	S	0.3	0.4	0.0	0.0	0.0	0.5	1.0	0.655
		T	0.2	0.4	0.0	0.0	0.0	0.5	1.0	
3	MBL	S	0.1	0.1	0.0	0.0	0.0	0.2	0.3	0.461
		T	0.1	0.3	0.0	0.0	0.0	0.2	0.7	
	mPI	S	0.3	0.5	0.0	0.0	0.0	0.3	1.8	0.854
		T	0.3	0.5	0.0	0.0	0.2	0.5	1.5	
	mBI	S	0.2	0.3	0.0	0.0	0.0	0.3	0.8	0.414
		T	0.3	0.4	0.0	0.0	0.0	0.5	1.3	
4	MBL	S	0.1	0.2	0.0	0.0	0.1	0.2	0.6	0.684
		T	0.1	0.3	0.0	0.0	0.0	0.2	0.7	
	mPI	S	0.1	0.2	0.0	0.0	0.0	0.2	0.5	0.317
		T	0.1	0.2	0.0	0.0	0.0	0.3	0.5	
	mBI	S	0.1	0.2	0.0	0.0	0.0	0.2	0.5	0.180
		T	0.2	0.3	0.0	0.0	0.0	0.5	0.8	
5	MBL	S	0.2	0.4	0.0	0.0	0.1	0.3	1.3	0.833
		T	0.2	0.3	0.0	0.0	0.0	0.4	0.7	
	mPI	S	0.3	0.3	0.0	0.0	0.3	0.5	1.0	0.414
		T	0.2	0.3	0.0	0.0	0.2	0.5	1.0	
	mBI	S	0.3	0.4	0.0	0.0	0.0	0.5	1.0	0.317
		T	0.2	0.3	0.0	0.0	0.0	0.3	1.0	

Level of significance (P<0.05).
12 implants per type (S and T).
MBL: marginal bone level, mPI: modified plaque index, mBI: modified bleeding index, SD: standard deviation, S: Astra Tech Osseospeed ™ 4.0s implant, T: Astra Tech Osseospeed ™ 5.0 implant.

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Table 3. *Post hoc* Wilcoxon signed rank test of marginal bone loss by time (*P* value [adjusted level of significance])

Type	Baseline	1 year	2 years	3 years	4 years	5 years
S	└0.034 (0.005)┘					
		└0.157 (0.015)┘				
			└0.317 (0.025)┘			
				└0.102 (0.010)┘		
					└0.317 (0.025)┘	
T	└0.180 (0.020)┘					
		└0.180 (0.020)┘				
			└0.102 (0.010)┘			
				└1.000 (0.030)┘		
					└0.317 (0.025)┘	

The adjusted level of significance was calculated using the Benjamini-Hochberg adjustment based on a level of significance of <0.05.
S: Astra Tech Osseospeed ™ 4.0s implant, T: Astra Tech Osseospeed ™ 5.0 implant.

Table 4. Marginal bone level changes between baseline and at 1, 2, 3, 4 and 5 years after prosthesis delivery according to jaw location

Year	Position	Mean	SD	Min.	1st Quartile	Median	3rd Quartile	Max.	Mann-Whitney test (*P* value)
1	Maxilla	0.1	0.2	0.0	0.0	0.0	0.3	0.5	0.697
	Mandible	0.0	0.0	0.0	0.0	0.0	0.1	0.1	
2	Maxilla	0.1	0.2	0.0	0.0	0.1	0.3	0.5	0.528
	Mandible	0.0	0.1	0.0	0.0	0.0	0.1	0.2	
3	Maxilla	0.2	0.2	0.0	0.0	0.1	0.3	0.7	0.452
	Mandible	0.0	0.1	0.0	0.0	0.0	0.1	0.2	
4	Maxilla	0.2	0.3	0.0	0.0	0.1	0.5	0.7	0.881
	Mandible	0.1	0.1	0.0	0.0	0.0	0.2	0.3	
5	Maxilla	0.3	0.3	0.0	0.0	0.1	0.6	0.7	1.000
	Mandible	0.2	0.4	0.0	0.0	0.0	0.3	1.3	

Level of significance (*P*<0.05).
16 implants in the maxilla and 8 implants in the mandible.
SD: standard deviation.

Evaluation of peri-implant soft tissue

The mPI and mBI were recorded every year after loading, and the results of the Wilcoxon signed rank test comparing the values are listed in **Table 2**. Our analysis showed no statistically significant differences between the S and T implants in mPI (S: 0.3±0.3 vs. T: 0.2±0.3; *P*=0.414) or mBI (S: 0.3±0.4 vs. T: 0.2±0.3; *P*=0.317) at 5 years after prosthesis delivery.

Evaluation of the correlation between the ID and marginal bone loss

Pearson correlation analysis was performed to determine the relationship between the ID, which was defined as the shortest distance between the S and T implants, and marginal bone loss on the inter-implant side of each type of implant (Si and Ti) (**Table 5**). We did not find significant correlations between ID and Si (*P*=0.684) or between ID and Ti (*P*=0.649) at 5 years after prosthesis delivery. In addition, there was no difference in marginal bone loss between the group with an ID ≥3 mm (0.1±0.1 mm) and the group with an ID <3 mm (0.2±0.4 mm) (*P*=0.864) at 5 years after functional loading.

Table 5. Pearson correlation coefficients between Inter-implant distance and marginal bone loss at the inter-implant side

Year	S		T	
	Correlation coefficient	*P* value	Correlation coefficient	*P* value
1	−0.2	0.500	−0.3	0.351
2	−0.1	0.711	−0.3	0.351
3	0.0	0.987	−0.3	0.351
4	−0.1	0.684	−0.3	0.351
5	−0.1	0.684	−0.1	0.649

Level of significance (*P*<0.05).
12 implants per type (S and T).
S: Astra Tech Osseospeed ™ 4.0s implant, T: Astra Tech Osseospeed ™ 5.0 implant.

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DISCUSSION

The purpose of this study was to compare marginal bone loss, mPI, and mBI between straight and tapered implants.

In this study, there were no significant differences between the S and T implants at any time point in terms of marginal bone loss. Five years after functional loading, marginal bone loss was 0.2±0.4 mm in the S implants and 0.2±0.3 mm in the T implants, which are relatively very small amounts compared to other studies on implants (1 year: 3.3±1 mm, 2 years: 3.8±1.2 mm in Quirynen et al. [2] 1992; 1 year: 1.14±0.54 mm, 2 years: 1.05±0.41 mm, 3 years: 1.86±0.35 mm in Malevez et al. [21] 1996). However, some studies have reported values similar to those observed in this study (1 year: 0.05±0.11 mm in Nordin et al. [22] 1998; 1 year: 0.14±0.11 mm, 2 years: 0.21±0.13 mm, 3 years: 0.24±0.13 mm in Lee et al. [10] 2007; 1 year: 0.06±0.67 mm, 2 years: 0.14±1.06 mm, 3 years: 0.07±0.84 mm, 4 years: 0.14±1.01 mm, 5 years: 0.14±1.04 mm in Wennström et al. [23] 2005). The difference between the 2 sets of prior studies is that the former studies used a flat-top design and machined surface, which has no retentive elements at the implant neck area. Instead, the latter studies used a conical interface design with a rough surface and retentive element at the implant neck area. The implants used in our study had similar characteristics to the latter studies, and similarly showed much lower amounts of marginal bone loss than the former studies.

This difference in the level of marginal bone loss can be due to various reasons, the first being the retentive element at the implant neck area. Implants with a micro-thread at the conical neck area were used in this study. The presence of a rough surface and retentive element at the implant neck is known to help reduce marginal bone loss [24]. Specifically, small threads appear to be useful in preserving marginal bone according to a finite element analysis study [25]. This finding is also supported by clinical study results showing small amounts of marginal bone loss in implants with micro-threads [26]. Another reason could be the conical implant-abutment interface. When compared to a flat-top interface, a conical interface delivers force deeper into the bone and reduces peak stress on the marginal bone [27]. This effect is supported by other investigations on marginal bone loss in implants with a conical interface [28,29], as well as a meta-analysis [30] that found a MBL change of -0.24 mm (95% confidence interval, −0.345 to −0.135 mm) over 5 years after loading in implants with the above characteristics. Due to these characteristics, there was a very small amount of marginal bone loss in this study, and the differences between conical and straight implant neck designs appeared minimal.

Although tapered implants distribute occlusal loads better than straight implants [31], the effect of occlusal loads on marginal bone loss lacks evidence [32]. This might help explain the lack of a difference in marginal bone loss difference between the tapered and straight implants.

In addition to the previous study, which recorded marginal bone loss in the first year after loading [1], this study recorded the values for the first 5 years after loading, making it possible to analyze differences over time and to study interactions between implant type (S and T) and time. The analysis using the nparLD package showed no interactions between type and time, meaning that there was no difference in the marginal bone loss pattern between tapered and straight implants. However, the differences in marginal bone loss over time were statistically significant, and a *post hoc* analysis was done to find the exact time at which the difference occurred. None of the time interval values were statistically significant, which indicates that

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gradual marginal bone loss took place and no specific time interval showed rapid progression of marginal bone loss.

As indicators of soft tissue status, mPI and mBI showed similar values to those seen in a previous study [33], with values of almost 0 and 1. These values mean that the peri-implant soft tissue was healthy, which might have been achieved by regular follow-up with professional plaque control and oral hygiene instruction [34]. More importantly, there were no differences between the S and T implants in either parameter at any of the time points tested. We can thus infer that there were no significantly different effects between tapered and straight implants in terms of peri-implant soft tissue.

Additionally, the ID was not standardized in this study, although other factors such as surface treatment, implant-abutment interface, and the retentive element were standardized. A previous study showed a negative association between ID and peri-implant marginal bone loss, especially when the ID was shorter than 3 mm [35]. However, this study showed no correlations between ID and marginal bone loss at the proximal side during the 5-year period after loading. In addition, there was no significant difference in marginal bone loss at the proximal side according to whether the ID was ≥3 mm or <3 mm. These results correspond with another previous study [36]. Therefore, this unstandardized factor can be excluded from consideration.

A previous study found that there was no difference in the implant survival rate between the maxilla and mandible [37]. However, another study showed a statistically significant difference in peri-implant marginal bone loss [38], which was larger in the maxilla than in the mandible. In this study, the survival rate and marginal bone loss were not different between the maxilla and mandible. Although not statistically significant, the mean values for the maxilla were larger than those for the mandible during the 5-year study period, implying that the lack of statistical significance may have been due to the small sample size.

There are some limitations to the study, such as a small sample of data and the skewness of the data. Further studies are needed to validate these results and to clarify the effects of different implant designs on marginal bone loss.

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