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Biomechanical Effects of Diameters of Implant Body and Implant Platform in Bone Strain around an Immediately Loaded Dental Implant with Platform Switching Concept

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Abstract: Dental implants designed with platform switching have been used clinically to reduce crestal bone resorption. The aim of this study was to determine the biomechanical effects of loading types, diameter of platform, and implant diameter in bone strain around immediately loaded implants with platform switching concept. Platform-switching features of dental implants with various diameters of implant body and implant platform (named as RP5.0, RP4.3, and NP3.5) were inserted into artificial bone blocks. The initial implant stability was confirmed using a Periotest device before the loading test. Rosette strain gauges were placed on the alveolar region around the implants, and peak values of the bone strain during a 190-N vertical load or 30-degree lateral load were measured by a data acquisition system. The Kruskal-Wallis test and post-hoc pairwise comparisons were performed as statistical analyses. The median Periotest values of the RP5.0, RP4.3, and NP3.5 implants ranged from −6.59 to −7.34. The RP5.0 implant always showed the lowest bone strain around the implant, regardless of whether a vertical or lateral load was applied. Relative to the RP4.3 and NP3.5 implants, the RP4.3 implant produced a higher bone strain (by approximately 8%) under a vertical load but a lower bone strain (by approximately 25%) under a lateral load. This study confirmed that using a wider implant could relieve the bone strain around an immediately loaded implant with platform switching concept especially under lateral loading.

Keywords: implant diameter; platform switching; immediately loaded dental implant; bone strain; strain gauge analysis

1. Introduction

The dental implant has been a common treatment for missing teeth. The main material of a dental implant is titanium, which displays well-documented mechanical properties and biocompatibility [1] that allows the process of osseointegration between bone and dental implant and provides stability when biting forces are applied. Recent clinical studies have reported the success rate of dental implant to be upwards of 95% [2] and both the periodontal [3] and biomechanical causes [1] affect the peri-implant tissue.

The esthetics of dental implants is affected by the peri-implant soft tissue and the underlying crestal bone [4–6]. Different implant characteristics such as its size, material (titanium vs. zirconia), roughness, surface modification (including grit-blasting, acid-etching, and anodization [7]), thread design, connection, and the prosthetic abutment design can influence the stress around immediately loaded implants [8–13]. It has been found that immediate occlusal loading applies to the implant within two weeks of implant insertion before osseointegration [14]. For example, it was found that the strain was concentrated in the cortical bone around the implant neck and was influenced by the diameter of the implant [10,15,16].

The design of platform switching [17] involves the implant-abutment interface being horizontally repositioned inwardly by using a prosthetic abutment with a smaller diameter, and this has been found to be beneficial by leaving less vertical distance necessary to establish the peri-implant biological width. The loss of crestal bone height is therefore inversely related to the discrepancy between the prosthetic abutment and the implant [18,19] and it has been confirmed that the design of platform matching preserves peri-implant bone by a measurable degree [2,20].

In addition to this biological advantage, from the biomechanical point of view platform switching will decrease the stress in the bone surrounding an implant [21,22]. The stress transmitted to the crestal bone was found to decrease when the prosthetic abutment diameter was reduced by 10% (to 4.5 mm) or 20% (to 4.0 mm) using 5 mm × 13 mm implants, regardless of the presence of microthreads or a smooth surface or the direction of the applied force (90 or 15 degrees) [23]. However, only a few studies have investigated the biomechanics of the design concept of platform switching in immediately loaded implants [9,13].

This study used NobelActive (NA) implants (Nobel Biocare, Gothenburg, Sweden) to investigate the biomechanical effects of the design of platform switching as well as implant diameter in peri-implant bone. According to previous studies, the design of the NA implant—featuring self-tapping and bone-compressing properties—can increase its primary stability and potentially makes this kind of implant more suitable for immediate placement in fresh extraction sockets and where immediate loading is applied [24–27]. The NA implant contains a built-in platform switching concept aimed at peri-implant bone maintenance; however, it is not yet well understood whether this implant affects the biomechanical environment of peri-implant bone.

The purpose of this study was to elucidate the effects of loading types, diameter of platform, and implant diameter on peri-implant bone strain, especially for an immediately loaded implant with the design concept of platform switching.

2. Materials and Methods

An in vitro experimental test including Periotest and strain gauge analyses was used to examine the influences of platform switching and implant diameter on the primary implant stability and the bone strain around immediately loaded implants. NA implants with a length of 11.5 mm and diameters of 3.5 mm, 4.3 mm, and 5.0 mm were employed (Figure 1), and designated as the NP3.5, RP4.3, and RP5.0 implants, respectively; the diameters of their corresponding abutments (Snappy™ abutment, Nobel Biocare, Göteborg, Sweden) are 3.0 mm, 3.4 mm, and 3.4 mm, respectively. Although the RP4.3 and RP5.0 implants had different diameters, their implant platforms were both 3.9 mm in diameter, which means that they possessed the same degree of platform switching in 0.5 mm after using a 3.4-mm-diameter abutment. The platform of NP3.5 implant was also 3.5 mm. Because the length of platform switching was obtained by subtracting diameter of abutment from diameter of implant platform, the NP3.5, RP4.3, and RP5.0 implants all had the same degree of platform switching (0.5 mm).

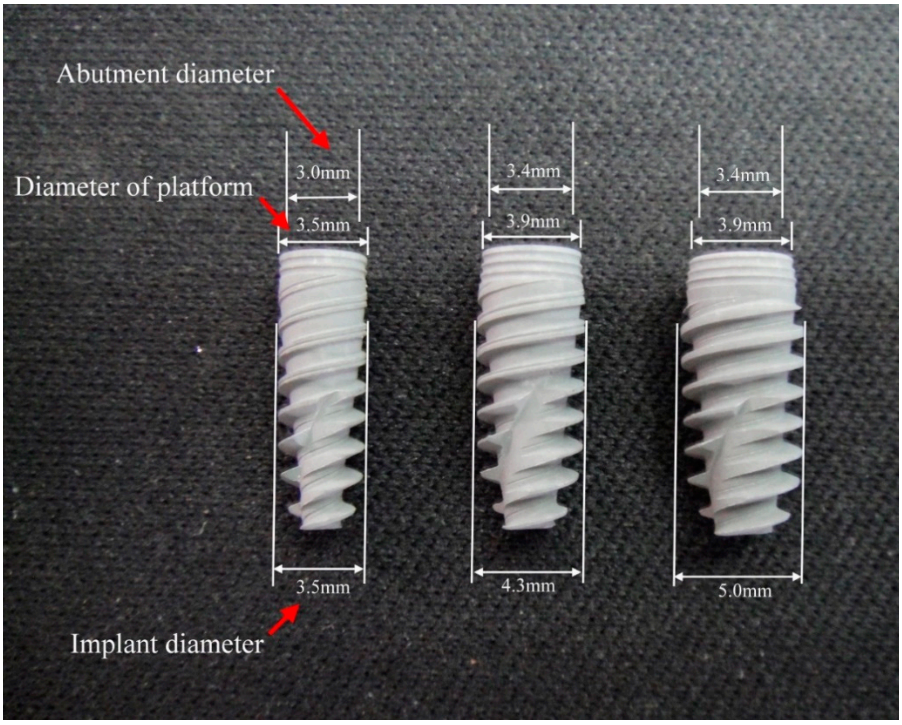

Figure 1. The RP5.0, RP4.3, and NP3.5 implants (from right to left).

Three specimens of rectangular synthetic trabecular bone (Sawbones model 1522-05, Pacific Research Laboratories, Vashon Island, WA, USA) were prepared for each implant group. The model of the trabecular bone with a density of 0.4 g/cm^3 and elastic modulus of 759 MPa was employed to simulate Misch's type 2 (D2) bone [28,29]. A 2-mm-thick synthetic cortical layer (Sawbones model 3401-02, Pacific Research Laboratories, Vashon, WA, USA) with an elastic modulus of 16.7 GPa was then attached to the top of the trabecular bone to complete the preparation of the experimental bone model. The dimensions of each experimental bone model were around 45 mm × 30 mm × 43 mm (Figure 2).

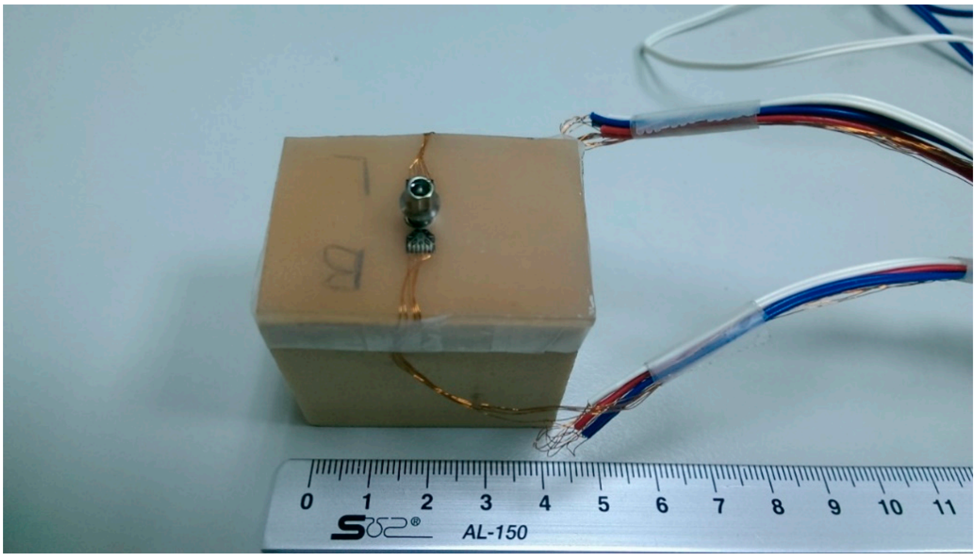

Figure 2. An experimental bone block with a 2-mm-thick synthetic cortical bone shell was prepared. After the implant was placed in the bone block, two rectangular rosette strain gauges were fixed onto the crestal cortical region near the buccal (B) and lingual (L) sides of the implant.

In order to simulate an immediately loaded implant, the interface between the implant and bone was prepared for contact only. After inserting the implants into the bone block and connecting titanium prosthetic abutments to the implants, the device of Periotest (Periotest Classic, Medizintechnik Gulden, Modautal, Germany) was used to measure the mobility of the implant. Periotest is one of the clinical noninvasive techniques and is easy to be used; therefore it is favorable for dentists to determine the initial implant stability after implantation. The process of the measurement was as follows: The tip of the device was perpendicularly positioned 2 mm from the prosthetic abutments and the instrument delivered calibrated impacts via a piston to the abutment four times per second for 4 s [30] as seen in Figure 3. Periotest values (PTVs) were obtained four times in each of four directions (buccal, lingual, mesial, and distal) for each model.

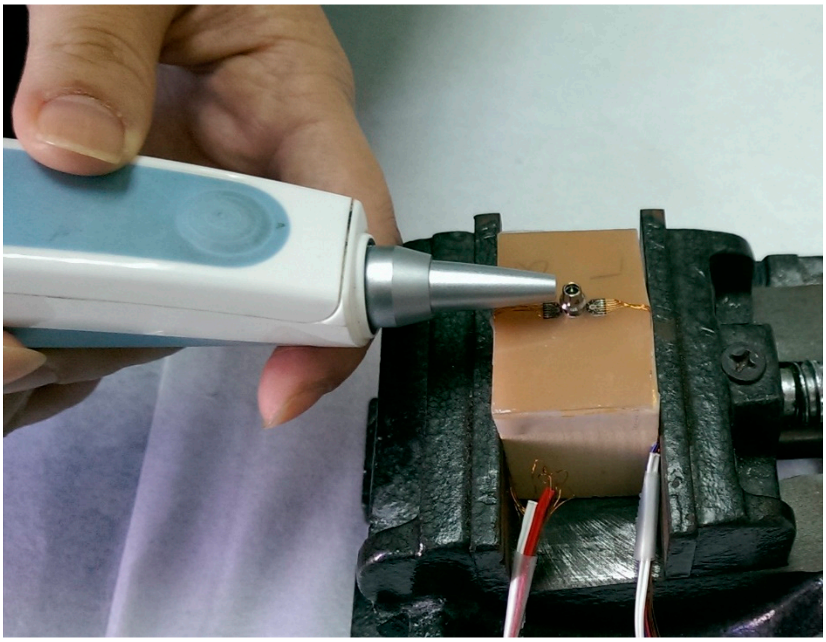

Figure 3. Periotest values were measured to ensure that each implant exhibited ideal primary implant stability before performing the strain gauge analysis.

Two kinds of occlusal loading—a vertical force and a 30degree lateral force—were applied to the prosthetic abutments by a universal testing machine (JSV-H1000, Japan Instrumentation System, Nara, Japan) with a custom-made jig as seen in Figure 4. Both kinds of forces had a magnitude of 190 N [31], and the head speed when applying the loads was 1 mm/min.

Rectangular rosette strain gauges (FR-1A12L30W05MS, Minebea Company, Tokyo, Japan) were attached to the crestal cortical region with cyanoacrylate cement (CC-33A, Kyowa Electronic Instruments, Tokyo, Japan) on both the buccal and lingual sides of the implant as seen in Figure 2. Signals of the three independent microstrains (ε_a, ε_b, and ε_c) recorded by the rosette strain gauge were sent to a data acquisition system (NI CompackDAQ, National Instruments, Austin, TX, USA) and analyzed by the associated software (LabVIEW SignalExpress 3.0, National Instruments, Austin, TX, USA) as seen in Figure 4. Each measurement was repeated three times for each specimen, and the maximum (ε_{max}) and minimum (ε_{min}) principal microstrains were obtained as follows:

$$\varepsilon_{max} = 1/2(\varepsilon_a + \varepsilon_c) + 1/2\sqrt{[(\varepsilon_a - \varepsilon_c)^2 + (2\varepsilon_b - \varepsilon_a - \varepsilon_c)^2]} \quad (1)$$

$$\varepsilon_{min} = 1/2(\varepsilon_a + \varepsilon_c) - 1/2\sqrt{[(\varepsilon_a - \varepsilon_c)^2 + (2\varepsilon_b - \varepsilon_a - \varepsilon_c)^2]} \quad (2)$$

Each of the three experimental groups included three experimental specimens. Therefore, there were a total of nine experimental specimens in this study. For each experimental specimen, five measurement values were obtained for statistical analysis. The measured PTV and the peak values of the principal microstrains of bone under vertical and lateral loading are presented as median ± interquartile range (IQR) values. The Kruskal-Wallis test was used to compare differences among the three groups of models. Post-hoc pairwise comparisons were conducted using Mann-Whitney exact tests with the Bonferroni adjustment, with the significance level set at 0.0167 (=0.05/3). All statistical analyses were performed using SPSS (version 19, IBM Corporation, Armonk, NY, USA).

Figure 4. A vertical force (**a**) and a 30-degree lingual lateral force (**b**) were applied as loading conditions by a universal testing machine (**c**). The microstrain signals were acquired by a data acquisition system.

3. Results

3.1. Periotest

The PTV (Table 1) was lowest for the RP5.0 implant, indicating the highest primary implant stability, and did not differ significantly between the RP4.3 and RP3.0 implants. All three implant groups exhibited good primary implant stability, allowing the next stage of the experiment (strain gauge analysis) to be performed.

Table 1. Periotest values * of the RP5.0, RP4.3, and NP3.5 implants.

Implant	PTV
RP5.0	−7.4 [a] ± 0.3
RP4.3	−6.7 [b] ± 1.2
NP3.5	−7.2 [a] ± 0.5
$p^{\dagger}$	0.012

Data are median ± interquartile range (IQR) values. † Kruskal-Wallis test. * Post-hoc pairwise comparisons were conducted by the Mann-Whitney exact tests with the Bonferroni adjustment; medians with the same letter [a,b] are not significantly different at the 0.0167 (0.05/3) level.

3.2. Strain Gauge Analysis

Under vertical loading, the strain in the bone around the implant was lowest for the RP5.0 implant, being 36% and 13% lower than for the RP4.0 and NP3.5 implants, respectively. The bone strain did not differ significantly between the RP4.3 and NP3.5 implants (Table 2).

Table 2. The minimum principal strains * of bone on the buccal and lingual sides for the RP5.0, RP4.3, and NP3.5 implants.

Analyzed Parameters		Microstrain	
Loading	Implant	Buccal Side	Lingual Side
Vertical loading	RP5.0	−1354.56 [a] ± 122.09	−1287.33 [a] ± 154.08
	RP4.3	−1782.62 [b] ± 248.95	−1836.10 [b] ± 216.51
	NP3.5	−1523.94 [b] ± 413.68	−1521.28 [b] ± 669.69
$p^{\dagger}$		<0.001	<0.001
Lateral loading	RP5.0	−685.95 [a] ± 96.46	−1542.82 [a] ± 337.75
	RP4.3	−1042.60 [b] ± 192.26	−2073.27 [b] ± 293.83
	NP3.5	−845.66 [b] ± 543.16	−2915.04 [c] ± 477.93
$p^{\dagger}$		<0.001	<0.001

Data are median ± IQR values. † Kruskal-Wallis test. * Post-hoc pairwise comparisons were conducted by the Mann-Whitney exact tests with the Bonferroni adjustment; medians with the same letter [a,b,c] are not significantly different at the 0.0167 (0.05/3) level.

Upon lateral loading, the strain in the bone around the implant was highest for the NP3.5 implant (−2915.04 ± 477.93), followed by the RP4.3 implant (40% lower) and the RP5.0 implant (89% lower).

4. Discussion

The diameter of the implant platform is the same (3.9 mm) for both the RP4.3 and RP5.0 implants, and so using a prosthetic abutment of the same diameter (3.4 mm) results in the same degree of platform switching (0.5 mm). This affects the marginal bone height [19,23], and results in the same platform switching components for RP4.3 and RP5.0 implants. For NP3.5 implants the degree of platform switching is also 0.5 mm, with a platform and implant diameter of 3.5 mm.

When comparing the RP4.3 and RP5.0 implants, which have the same diameter of implant platform (3.9 mm) and the same degree of platform switching (0.5 mm), the effect of implant diameter cannot be ignored during both vertical and lateral loading. The larger diameter of the RP5.0 implant resulted in lower strain levels than for the RP4.3 implant in peri-implant bone. Previous studies have found the strain to be highest at the marginal bone nearby the implant, which reduces when the implant diameter is increased [16,32]. This might indicate that the diameter of the implant greatly influences the strain irrespective of the diameter of implant platform and whether or not platform switching is applied.

While the RP3.5 and NP4.3 implants both have different implant and implant platform diameters, the degree of platform switching is the same (0.5 mm). Under lateral loading, the strain was higher for the NP3.5 implant, which may be due to its smaller implant body or smaller diameter of implant platform. This may indicate that similar to the effect of implant diameter, the diameter of the implant platform also greatly influences the stress applied on the coronal cortical bone in our experiment, and may also be highly involved in reducing the strain.

A particularly interesting finding was that during vertical loading, the strain on the bone was higher around the RP4.3 implant than around the NP3.5 implant despite the former having larger implant and platform diameters. These results indicate that the combined influences of the implant diameter and the diameter of implant platform in bone strain around an immediately loaded implant might differ with the type of loading (e.g., vertical vs. lateral), especially for small-diameter implants given that the smaller-diameter RP3.5 implant showed lower bone strain than the NP4.3 implant under vertical loading.

In order to avoid the possible confounding factor of individual differences in the characteristics of human jawbones, the present study used artificial bone specimens as testing samples. Although the porosities of artificial bone specimens are fairly consistent and their material properties are similar to those of human bone, further researches should consider performing cadaveric or animal tests. Other limitations were the dynamic loading [33] and other abutment-implant connection designs [34] for partial or complete dentures which were not considered in this study. If any further study is performed in the future, these factors may need to be included for study completeness.

5. Conclusions

While the combined influences of diameter and platform switching concept of titanium dental implant on bone strain vary with the type of loading (vertical vs. lateral loading), embedding a wider diameter of implant into bone is obviously beneficial in decreasing the bone strain around immediately loaded dental implant with platform switching concept.

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Conflicts of Interest: All authors declare that they have no conflict of interest.

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