



A comparative biomechanical study of original and compatible titanium bases: evaluation of screw loosening and 3D-crown displacement following cyclic loading analysis

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PURPOSE. This study evaluated screw loosening and 3D crown displacement after cyclic loading of implant-supported incisor crowns cemented with original titanium bases or with three compatible, nonoriginal components. **MATERIALS AND METHODS.** A total of 32 dental implants were divided into four groups (n = 8 each): Group 1 used original titanium bases, while Groups 2-4 used compatible components. The reverse torque value (RTV) was evaluated prior to and after cyclic loading (1,200,000 cycles). Samples (prior to and after cyclic loading) were scanned with a microcomputed tomography (micro-CT). Preload and postload files were superimposed by 3D inspection software, and 3D crown displacement analysis was performed using root-mean-square (RMS) values. All datasets were analyzed using one-way ANOVA and Tukey's post hoc analysis. **RESULTS.** Significant variations were observed in the postload RTV, depending on the titanium base brand ($P < .001$). The mean postload RTVs were significantly higher in Groups 1 and 2 than in the other study groups. While evaluating 3D crown displacement, the lowest mean RMS value was shown in the original Group 1, with the highest RMS value occurring in Group 4. **CONCLUSION.** Within the limitations of this *in vitro* study and under the implemented conditions, it was concluded that the manufacturer brand of the titanium base significantly influenced screw loosening following the fatigue test and influenced 3D crown displacement after cyclic loading. [J Adv Prosthodont 2022;14:70-7]

KEYWORDS

Dental implant; Dental abutment; X-ray microtomography; Torque; Crown

INTRODUCTION

The connection between a dental implant and a titanium base is a clamped joint. The stability of this joint depends on multiple factors, including the ma-

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ching accuracy/tolerance profile, component uniformity, material properties, abutment screw type, and implant-abutment connection type.¹⁻⁴ Components produced by different manufacturers are made with different machining microtolerances, resulting in design/dimensional accuracy discrepancies.⁵ Misfit can be defined as a 3D gap between a titanium base and an implant^{6,7} and can lead to micromotion,⁸ causing wear of the mating surfaces⁹ and screw loosening.^{1,4,10} Thus, an indicator of implant-abutment connection stability is maintenance of the reverse torque value (RTV) during cyclic loading.¹¹ Several studies have investigated abutment axial displacement following cyclic loading¹² and 3D-crown displacement following screw tightening.¹³ However, no previous study has investigated the influence of oblique (30°) cyclic loading on 3D anterior crown displacement when cemented with different brands of titanium bases. Thus, it was hypothesized that embedment and wearing of mating surfaces lead to abutment together with crown 3D displacement during cyclic loading.

Titanium bases are versatile prosthetic components for implants.¹⁴ From one perspective, different material (zirconia, lithium disilicate, porcelain fused to metal) single- or multi-unit restorations can be cemented with bases. Conversely, a reliable connection with implants can be achieved.¹⁵ The use of nonoriginal prosthesis components in dental implants has become popular for economic reasons.

This study aimed to compare biomechanical properties of original and compatible titanium bases. The initial study objective was to compare the postload RTV for varying titanium base groups. The secondary objective was to compare 3D-central incisor shaped crown displacement following cyclic loading of varying titanium base groups.

The first null hypothesis was that no differences would be identified in the postload RTV of various titanium base groups. The second null hypothesis was that no differences would be found in 3D crown displacement among different titanium base groups.

MATERIALS AND METHODS

A total of 32 internal-conical connection, with six indexing slots and commercially pure grade 2 titani-

um implants (3.5 × 11 mm Ankylos® C/X (Dentsply® Implants Manufacturing GmbH, Hanau, Germany)), were divided into four groups (n = 8 each) according to the manufacturer of the titanium base: (1) Ankylos® titanium base/X (Dentsply® Implants Manufacturing GmbH, Hanau, Germany); (2) Arum® titanium base with a regular pilar (Doowonid Co., Ltd., Daejeon, Korea); (3) IPD titanium base with a 1 mm gingival height (Implant Protesis Dental 2004 S.L., Mataró, Spain); and (4) Dess® titanium base with a 1.5 mm gingival height (Terrats Medical S.L., Barberà del Vallès, Spain) (Fig. 1). The abutment material was Ti-6Al-4V titanium alloy in all groups.

Exocad™ DentalCAD (Exocad GmbH; Darmstadt, Germany) software was used to create maxillary-central incisor anatomy crowns that were 11 mm long and 8.5 mm wide. Crowns were cast from 32 CAD-CAM wax patterns (Starbond CoS/Scheftner cobalt-chromium dental alloy). Bonding surfaces were sandblasted with aluminum oxide (50 μm grain size), except for the titanium bases in Group 4, which were industrially sandblasted with aluminum oxide (50 μm grain size) particles. Crowns were cemented with the self-adhesive resin cement Breeze™ (Pentron Clinical Technologies, LLC, Wallingford, CT, USA) according to the manufacturer's recommendations.

Following the cementing step for each crown, the titanium base assembly was connected to the implant. The application of a 15 Ncm insertion torque was performed twice using a digital torque gauge (PCE-TM 80; PCE Instruments, Meschede, Germany) at an interval of 10 min to minimize possible embedment relaxation. RTVs were obtained after an additional 10 min period without fatigue loading to determine the initial RTV. Then, identical tightening and retightening forces were applied. Following cyclic loading, postload RTV was measured as previously described.^{1,10} Tightening and measuring were performed by the same operator. To calculate the percentage of torque loss when compared to the applied torque, the following formula was used¹:

$$\text{Torque loss \%} = \frac{\text{RTV} \times 100}{\text{insertion torque}} - 100$$

Samples underwent 1,200,000 chewing cycles and a force of 50 N (approx. 11 lbf or 5 kgf) in a chewing

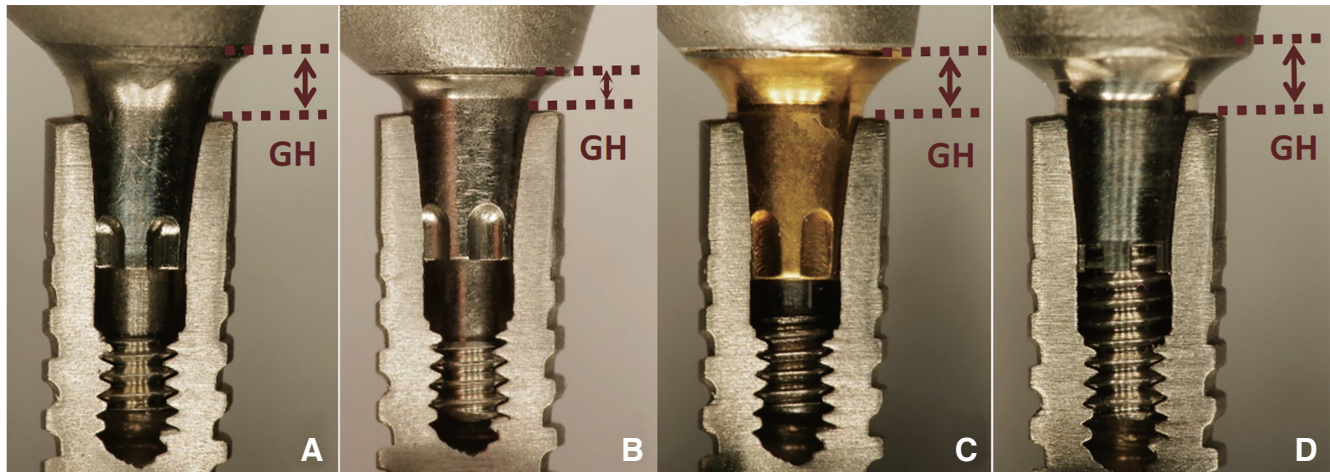


Fig. 1. Titanium bases design features. Groups 1-3 (A, B, C, respectively): six cams and grooves act as a positional index. In Group 4 (D) a positional index consists of six fingers. The gingival height (GH) of Groups 1-4 was 1.3, 0.7, 1.1 and 1.3 mm, respectively.

simulator, simulating approximately five years of clinical service within anterior dentition.^{15,16} Samples were embedded according to ISO 14801:2016 specifications. All implants were vertically embedded into the holding device 3 mm from the top platform of the holding device to simulate clinical bone loss. Samples were secured into the holders using Delo® SJ8665 glue (DELO, Windach, Germany). All samples were subjected to dynamic loading within a chewing simulator (CS-4.8; SD Mechatronik, Westerham, Germany) for 1,200,000 loading cycles. A loading force of 50 N was applied at an angle of 30° to the implant axis, 3 mm below the incisal edge on the palatal aspect of the crown, at a frequency of approximately 1.3 Hz, using a 3-mm-diameter stainless-steel ball (AISI 420 Grade 100). The GH of the titanium base did not affect the loading point. To simulate wet conditions within the oral cavity and to subject the crown to a wet environment, all specimens were soaked in distilled water at room temperature for the entire experimental run period. During the experiment, retightening was not performed. Cyclic loading and micro-CT scanning were performed at the SD Mechatronik Laboratory (Westerham, Germany).

Prior to the experiment, each implant/titanium base/crown complex was scanned using an X-ray microtomography SkyScan 1275 (Bruker MicroCT, Kontich, Belgium) to create a baseline. Scanning parameters were standardized at a tube voltage of 80 kV with

a tube current of 125 μ A using an aluminum filter. Each sample was scanned at a total angle of 180° and five frames/0.2° rotation. After postcyclic loading, micro-CT micrographs were reobtained for each sample. All images were collected as a 3D model and exported into an STL file.

To smooth the 3D models, the Mesh Doctor command was used (Geomagic Wrap®; 3D Systems, Rock Hill, SC, USA). All 3D analyses were performed with the 3D inspection software Geomagic® Control X™ (3D Systems, Rock Hill, SC, USA). The preload STL file was used as a reference dataset. The implant was split from the entire surface and used for best-fit alignment as a reference body (Fig. 2). To ensure that 3D crown displacement was measured equivalently between groups, each crown was cropped precisely above the titanium base. During 3D analysis, distances between surfaces of the preload and postload crowns were calculated as the RMS values for quantitative evaluation of the overall crown displacement.¹³ The RMS value was calculated using the following equation:

$$\text{RMS} = \frac{1}{\sqrt{n}} \times \sqrt{\sum_{i=1}^n (X_{1,i} - X_{2,i})^2}$$

where $X_{1,i}$ is the measuring point i on the reference data, $X_{2,i}$ is the measuring point i on the postload data, and n is the total number of measuring points per specimen. The RMS value demonstrates congru-

ency for the two superimposed files. A higher RMS value indicates a higher deviation of the crown, and a lower RMS value reveals a higher consistency of the initial and postload 3D crown positions.

Color-difference maps were used to visualize postload crown displacement. The area with deviations within the tolerance limit (max/min: $\pm 100 \mu\text{m}$) is shown in green; regions where the postload scanned data were larger or smaller than the initial-scanned data by a difference of $>100 \mu\text{m}$ are shown in yellow-to-red and light-to-dark blue, respectively.

Normal data distributions (initial RTV, postload RTV, and RMS values) were investigated using the Shapiro-Wilk normality test. Means and standard deviations were also calculated. To determine any variations due to the titanium base group, one-way ANOVA was performed, and Tukey's test was used for post hoc comparisons among all groups. The correlation between postload RTV and RMS values was evaluat-

ed using the Pearson correlation test. A *P* value of $< .050$ was considered statistically significant for all experimental methods. All datasets were analyzed using SPSS software version 27.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

In the present study, all samples survived 1,200,000 loading cycles. Table 1 shows the means, standard deviations, and percentages of initial and postload RTV. ANOVA results demonstrated that there was a significant variation among the initial and postload RTV means for the titanium base groups ($P < .001$). All RTVs were lower than the insertion torque, both prior to and after mechanical cycling. The smallest decrease in initial RTV was observed in Group 2. The smallest decrease in postload RTV mean was also observed in Group 2, while the most marked decrease

Fig. 2. Schematic illustration of initial and postload STL file 3D analyses: (A) preload STL file; (B) postload STL file; (C) split and best-fit aligned implant; and (D) 3D analysis of crown displacement.

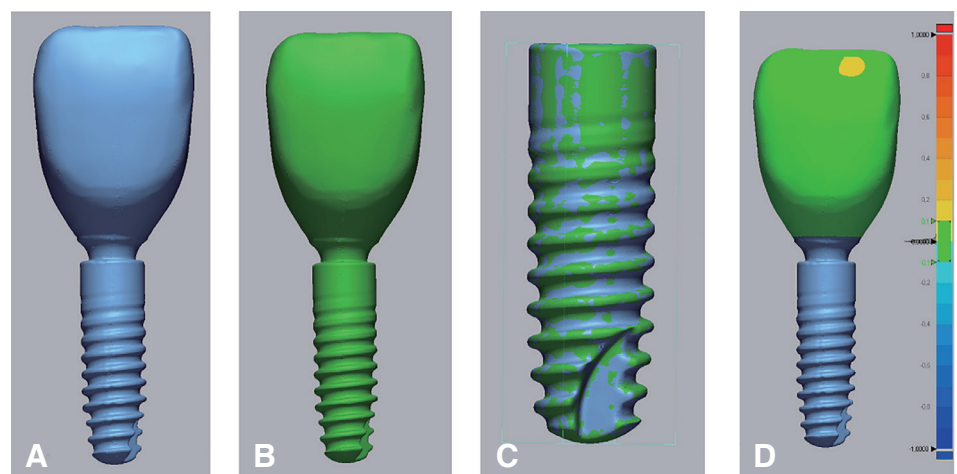


Table 1. Mean torques in Ncm with standard deviations (SDs) and percentages of torque loss for the titanium base implant screws. Initial RTV (after 10 min) and postload RTV (postloading in chewing simulator)

	Insertion torque	Initial RTV		Postload RTV	
		Mean \pm SD	% Torque loss	Mean	% Torque loss
Group 1	15	11.51 \pm 0.86 ^a	-23.25 ^a	8.26 \pm 1.24 ^a	-44.91 ^a
Group 2	15	13.16 \pm 0.64 ^b	-12.25 ^b	8.53 \pm 0.87 ^a	-43.08 ^a
Group 3	15	11.48 \pm 0.84 ^a	-23.41 ^a	6.22 \pm 1.41 ^b	-58.50 ^b
Group 4	15	10.95 \pm 1.00 ^a	-27.00 ^a	4.12 \pm 1.26 ^c	-72.50 ^c
Analysis type		<i>P</i> < .001	<i>P</i> < .001*	<i>P</i> < .001*	<i>P</i> < .001*

Values followed by identical lowercase letters in columns were not significantly different, according to Tukey's honest significant difference test ($P < .050$).

* $P < .001$, one-way ANOVA.

was observed in Group 4. As determined by a comparison of all postload RTVs, all groups varied significantly from each other except for Groups 1 and 2, which had significantly higher RTVs than Groups 3 and 4 (Tukey's test).

Detailed 3D analyses of the four titanium base groups revealed significant variations, depending on the base manufacturers ($P < .001$; one-way ANOVA). The original ($48.4 \pm 15 \mu\text{m}$) and Group 2 ($65.7 \pm 14 \mu\text{m}$) titanium bases exhibited a significantly lower 3D displacement relative to Group 3 ($88 \pm 12 \mu\text{m}$) and Group 4 ($93.7 \pm 18 \mu\text{m}$) ($P < .050$; Fig. 3). The Pearson correlation coefficient was -0.563 , suggesting a moderate negative correlation between postload RTV and 3D-crown displacement.

Figure 4 shows that barely observable 3D crown displacements of $>100 \mu\text{m}$ occurred in the original Group 1. In Groups 2 and 4, crown displacements of $>100 \mu\text{m}$ occurred buccolingually (i.e., in the direction of loading). In Group 3, buccolingual crown displacement occurred with counterclockwise rotation.

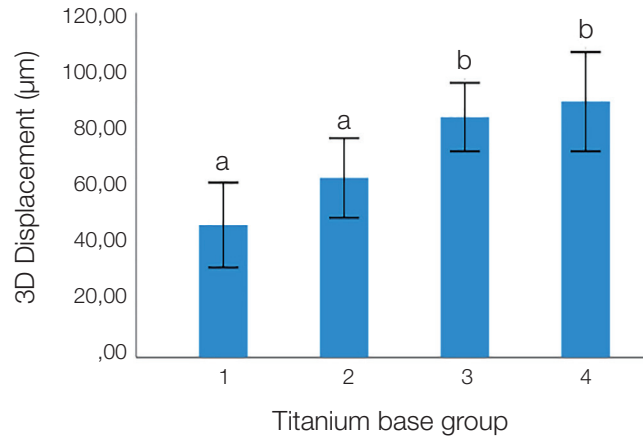


Fig. 3. Comparison of 3D crown displacement according to implant titanium base group. Data are shown as a function of the mean RMS value and 95.0% CI. Different lowercase letters indicate statistically significant differences according to Tukey's honest significant difference test ($P < .050$).

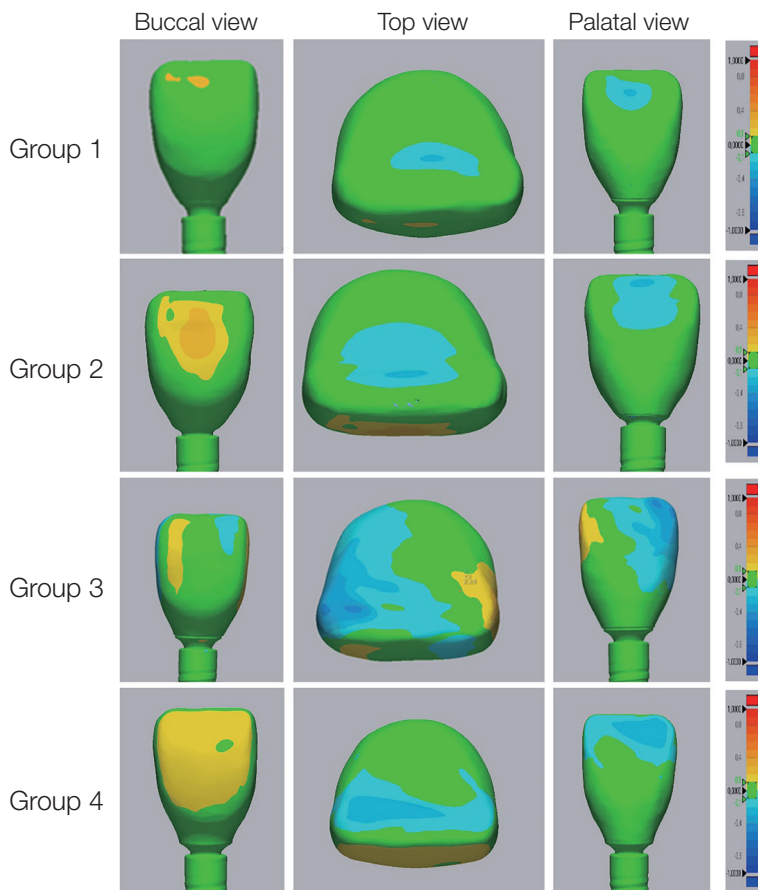


Fig. 4. Comparison of color-coded imaging data of the four different manufacturer brands of titanium bases (using a typical example from each group). A 3D inspection software was used to visualize 3D crown displacement.

DISCUSSION

The null hypothesis that no significant difference would be found in postload RTV between original and three generic titanium bases following dynamic loading was rejected. The null hypothesis that no significant differences would be found in 3D crown displacements following dynamic loading among different titanium base manufacturer brands was also rejected.

This study showed that the Group 1 (original) and Group 2 titanium bases exhibited lower postload RTV loss than Groups 3 and 4. In previous work, several authors found that original abutments presented lower values for screw loosening than non-originals.^{1,11,17} In addition, previous studies also found significant variations in the mean micro gap at the implant/abutment interface,^{18,19} leakage,^{20,21} and rotational misfit² between the original and other manufacturer brand abutment groups.

The loading scenario was 30° to the implant long axis. Due to nonaxial loading, the upper and lower titanium base connection parts acted as a lever.²² Loss of RTV and crown/titanium base displacement can be explained by embedment relaxation ('settling' effect)²³ and wear at the implant/titanium base interface. Each surface has microirregularities. This settling effect can be defined as flattening of microscopically rough high spots on the mating surfaces due to micromovements. As these microirregularities wear, the titanium base and implant internal surface move closer to each other. When the total embedment relaxation overwhelms the capacity for elastic elongation of the screw, clamping forces holding the screw in place no longer exist between the surfaces.¹² A total of 1,200,000 loading cycles caused small amplitude oscillatory motions at the implant/titanium base connection. This movement caused mating surface fretting wear.^{9,24} Blum *et al.*²² found chipping and plastic deformation at antirotational indices within the implant, following 1,000,000 cycles with a 98 N loading.

All crown/titanium base samples in this study had to be removed with pliers following cyclic loading. This can be explained by intrusion of the upper and lower titanium base connection surface into the im-

plant, although this justification cannot be fully confirmed by data from the present study.²²

Differing results among implant groups studied could indicate varying machining tolerance, surface irregularities, and material properties of titanium bases made by different manufacturers. Because torque maintenance capacity is a surrogate measure of abutment stability, Groups 1 and 2 were more stable than Groups 3 and 4.

The μ CT technique used in this study is a nondestructive, high-precision technique that allows 3D qualitative and quantitative evaluation of implants and prosthetic components.^{7,25,26}

The datasets demonstrated lower 3D crown displacements for Groups 1 and 2 than for Groups 3 and 4. Crown displacement is likely due to the wearing of the clamped joint contacting surface microirregularities and the settling effect. Crown rotation with buccolingual displacement in Group 3 may be a consequence of wear, screw loosening and rotational misfit between the titanium base and implant. Previously, a median rotation of 0.82° of Ankylos C/X implants' original abutments was found.²⁷ However, a 5.29° rotational freedom of abutments was found for another internal-conical connection implant system.²⁸ Screw loosening led to a gradual decrease in the clamping force, and the crown/titanium base rotated in the counterclockwise direction due to cyclic loading (in the same direction that the screw rotates while loosening). Moreover, Group 3 bases were anodized, which can significantly reduce the removal torque by approximately 20%.²⁹

The highest 3D crown displacement could occur in Group 4 due to the different connection design. Fingers instead of cams and grooves could be less resistant to oblique loading. The results of postload RTV are negatively correlated with the 3D crown displacement results. From a clinical perspective, 3D crown displacement can lead to a superstructure misfit, loss of crown at interproximal and occlusal contacts, and subsequent esthetic issues, particularly within the anterior region.³⁰

This study, however, contains several limitations. A higher GH of the titanium base may increase loading on the implant/titanium base joint due to a higher vertical cantilever. In our study, the lowest GH was

0.7 mm, and the highest was 1.3 mm. However, we assume that the effect of GH was minimal because in another study, a significant difference in postload RTV was found only between GHs of 1.5 and 5.5 mm across abutment groups after 50,000 75 N loading cycles.³¹ Another limitation of this study is that the predominant factors (i.e., screw properties, titanium base surface properties, design, machining tolerance) that caused screw loosening and crown displacement in each group were not clarified. Clinical research is required to evaluate RTV and any displacements *in vivo*. Because this study was conducted with a specific implant manufacturer *in vitro*, the results may not provide generalized conclusions that apply to other manufacturers' implants and titanium bases. However, periodic retightening of the titanium base screw should be used as a routine procedure in dental practice.

CONCLUSION

Within the limitations of this *in vitro* study, it can be concluded that the manufacturer brand of the titanium base significantly influenced screw loosening and 3D crown displacement following fatigue testing. According to the results, the selection of the titanium base manufacturer is important for long-term stability of implant/titanium base/crown complex.

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