Abutment Rotational Displacement of External Hexagon Implant System Under Lateral Cyclic Loading

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ABSTRACT

Purpose: This in vitro study investigated the effect of lateral cyclic loading with different load positions and periods on abutment rotational displacement (RD) of external hexagon implant system.

Materials and Methods: Four groups of five implant assemblies each were used. Each assembly consisted of Brånemark System® Mk IV implant (Nobel Biocare AB, Göteborg, Sweden), CeraOne® abutment (Nobel Biocare AB), and a cement-retained casting. A cyclic load of 50 N was applied centrally and perpendicular to the long axis of the implant for groups A and B for 0.25 and 0.50×10^6 cycles, respectively, while for groups C and D, the same load was applied at 4-mm distance eccentrically for 0.25 and 0.50×10^6 cycles, respectively. The displacement was evaluated by hand drawing a longitudinal line across the implant-abutment interface. Before and after loading, the lateral distance between two reference points on the abutment and implant was measured under high resolution (×200) and the difference formed the RD value. The data were analyzed with one-way analysis of variance and compared with Tukey test ($\alpha = 0.05$).

Results: Group D had the highest mean of RD value ($55.00 \pm 1.871\,\mu$m), while group A had the lowest ($2.800 \pm 0.837\,\mu$m). Groups A and B had a high statistically significant difference in RD values, as compared to groups C or D ($p < .001$). Moreover, group C had statistically significant difference from group D ($p = .011$). Conversely, no statistical significance was obtained when group A was compared with group B.

Conclusion: Within the limits of this in vitro study, the RD of the external hexagon joint components occurred significantly under eccentric lateral loading when compared to centric loading. The displacement increased significantly with longer period of eccentric lateral loading.

KEY WORDS: external hexagon implant, implant-abutment interface, lateral cyclic loading, rotational displacement

The original purpose of this 0.7-mm hexagon extension was to provide rotational torque transferring mechanism that secures the implant on its mount during the surgical placement into the bone at the implant receptor site. Recently, with the introduction of single-tooth implant applications, this purpose has been changed into a prosthesis indexing and antirotational mechanism.[1,2] Moreover, the implant hexagon extension is also used as an orientation device for impression coping to transfer the exact oral relationship of the implant to the working cast.[3]

Nobel Biocare AB (Göteborg, Sweden), the Brånemark® implant manufacturer, stated that "freedom of fit" between implant components, incorporated into their design, would allow horizontal and rotational

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movements in order to tolerate any horizontal fitting errors.[4] On the other hand, White[5] has reported that horizontal misfits can cause “implants and their internal screw parts to deform on tightening” and, consequently, affect the screw joint stability. In addition, rotational misfit at the implant–abutment hexagon interface has been considered as a major factor in screw joint failure.[6,7,8] In a study completed by Binon and McHugh,[7] the implant–abutment rotational misfit was reduced and the specimens underwent eccentric axial cyclic loading. The results indicated a direct correlation between the implant–abutment rotational misfit and screw loosening. They concluded that the elimination of rotational misfit would make the screw joint more resistive to screw loosening. In another study accomplished by Binon,[6] incrementally larger sizes of abutment hexagons with corresponding increased rotational misfits were cyclically loaded until joint failure occurred. The greater the size discrepancy, the greater the rotational misfit and smaller the flat-to-flat contact area at the implant-abutment interface. The results showed a direct correlation between the implant–abutment rotational misfit and screw joint failure. It was concluded that the tighter the fit between the implant hexagon extension and its abutment counterpart, the greater the number of cycles to screw joint failure.

Another study[9] investigated the influence of two patterns of lateral cyclic loading on the abutment screw loosening in a hexagon-mediated butt joint system. In this study, a 50-N lateral load was centrically applied to the first-group specimens for 1.0×10^6 cycles, whereas the same load was eccentrically applied to the second-group specimens in the untightening direction for 1.0×10^6 cycles. Before and after cyclic loading, the reverse torque of the abutment screw was measured and compared between the two loaded groups and the third unloaded group (control). The obtained data indicated that the centric loading decreased significantly the reverse torque, while the eccentric load affected insignificantly. These results might be related to the presence of play at the hexagon interface, which aggravated screw fatigue in the centric loading group. On the other hand, the eccentric lateral load made the implant hexagon engaged with the abutment counterpart and supplied a lock effect, which dispersed bending forces away from the abutment screw and reserved the screw torque.[9]

The implant hexagon extension height has been implicated as an important factor for maintaining antirotational stability of the screw joint.[1,2] English[1] reported that the external hexagon, theoretically, requires a minimum of 1.2 mm in height to attain optimal antirotational effect.

Single-molar implants might have a high susceptibility to bending overload and shearing stress at the implant–abutment screw joint.[10–15] However, no authors have yet reported on the abutment rotational displacement (RD) of the external hexagon implant systems under lateral cyclic loading. Therefore, this study was designed to investigate the effect of lateral cyclic loading with different load positions and periods on abutment RD over an implant of an external hexagon implant system.

MATERIALS AND METHODS

Twenty implant assemblies, each consisted of Brånemark System® Mk IV implant (4 × 10 mm) (Nobel Biocare AB) mounted in a semicylindrical brass block (25.4 × 17 mm), CeraOne® abutment (3 mm) (Nobel Biocare AB), and a cement-retained casting (7 × 10 × 7 mm). The implant was placed in the brass block and fixed by tightening the side screw with a screwdriver. The specimen preparation, casting fabrication, and cementation were described in previous studies.[9]

The implant assembly was held in place by a bench vice attached to a solid board. A torque gauge (Model BTG60CN, Tonichi Mfg. Co., Tokyo, Japan) was used to insure an accurate application of reproducible force to each abutment screw.[16,17] The handle for abutment screwdriver (UniGrip®, Nobel Biocare AB) was mounted in the three-jaw chuck of the torque gauge and then the corresponding machine driver was attached. The torque gauge was rotated clockwise until the abutment screw was tightened to 32 Ncm, that is, the recommended tightening for clinical application. Ten minutes later, the screw was retightened to the same torque to minimize embedment relaxation between the mating threads, and thus, help in achieving the optimum preload.[16,18]

Each specimen was mounted in a holder of a custom-made lever-type fatigue testing machine that was used in previous studies.[9,19,20] A cyclic load of 50 N was applied perpendicularly to the flat surface of the underlying abutment (Figure 1). The peak load was equivalent to the lateral component of a 100-N vertical force on a 30° cusp inclination to the longitudinal axis of the implant.[19] The loading rate was 75 cycles per

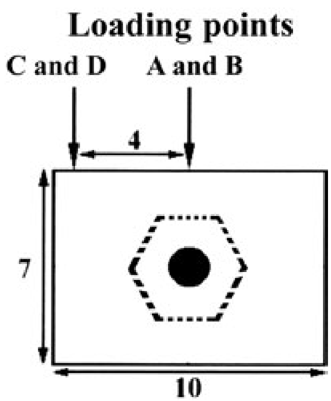

Figure 1 Schematic diagram showing the loading conditions for test groups from the top or occlusal view. The dotted hexagon represents the implant or abutment hexagon, and the central black circle indicates the screw head access hole for tightening.

minute that was similar to the human chewing frequency.[21]

The assemblies were divided into four groups (A, B, C, and D) of five specimens each. For groups A and B, the load was applied perpendicular to the implant long axis (0-mm off-axis) (see Figure 1). A target of 0.25×10^6 and 0.5×10^6 cycles was defined for groups A and B, respectively. For groups C and D, the same load was applied eccentrically distanced at 4 mm for 0.25×10^6 and 0.50×10^6 cycles, respectively.

Measurement of the RD of the Abutment

The abutment RD was evaluated by hand drawing a longitudinal line across the implant-abutment interface with a 0.5 mm–diameter marker (Mitsubishi Inc., Tokyo, Japan). Another two lateral lines, crossing the longitudinal one, were drawn on the implant head circumference and the lower part of the abutment collar (Figure 2). One of the pointed corner at the cross point of the two lines was considered the reference point for any displacement that can occur after loading. Before and after loading, the lateral distance between the two crossing (reference) points was measured for each specimen under high resolution (×200) with a micrometer microscope (profile projector, Nikon Inc., Tokyo, Japan), capable of 1-µm accuracy. The difference between the preload and postload distances was calculated. The distance difference was named postload RD of the abutment (in micrometers) and the results were then compared between the test groups.

Specimen preparation and testing were performed by the same operator and completed in random sequence to avoid potential errors due to an increase in the operator's skill. Furthermore, operator error was evaluated by measuring five replications of RD for randomly selected 10 specimens. Specimen variance for the replications ranged from 0 to 5.7×10^{-7} (average variance for the 10 specimens was 3.33×10^{-7}) and the SD ranged from 0 to .00068, indicating minimal operator error.

Statistical Analysis

It was hypothesized that under lateral cyclic loading, neither the centricity nor eccentricity of loading rotates the abutment over the implant. The mean values of RD, SDs, and SEM were calculated. The data for groups A, B, C, and D were analyzed with one-way analysis of variance (ANOVA) ($\alpha = .05$). Accordingly, all pairwise multiple comparison procedures using Tukey test ($p < .050$) were performed for the comparisons among individual means of the test groups.

RESULTS

Group D had the highest mean of RD value (55.00 ± 1.871 µm), while group A had the lowest (2.800 ± .837 µm) (Table 1). The results of one-way ANOVA, summarized in Table 2, demonstrated the presence of a

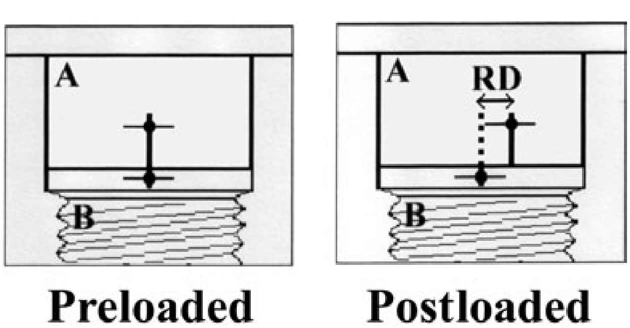

Figure 2 Schematic diagram showing preloaded and postloaded conditions an abutment (A) and implant (B) with a crossing hand-drawn vertical line and two horizontal lines. RD = rotational displacement.

TABLE 1 Means of Rotational Displacement, SDs, and SEM for the Test Groups

Group	*n*	Mean (µm)	SD (µm)	SEM (µm)
A	5	2.800	0.837	0.374
B	5	3.400	1.140	0.510
C	5	51.400	2.074	0.927
D	5	55.000	1.871	0.837

TABLE 2 One-Way Analysis of Variance ($p < .050$) for Groups A, B, and C

Source of Variation	*df*	SS	MS	F value	*p*
Between groups	3	12583.350	4194.450	1712.020	<.001
Residual	16	39.200	2.450		
Total	19	12622.550			

df = degree of freedom; MS = mean square; SS = sum of squares.

statistically significant difference with different load positions ($p < .001$). This primary analysis has rejected the null hypothesis as a significant effect was found between the test groups. The results of the Tukey test indicated that groups A and B had a high statistically significant difference in RD values, as compared to group C or D ($p < .001$) (Table 3). Moreover, group C had statistically significant difference from group D ($p = .011$). Conversely, no statistical significance was obtained when group A was compared with group B.

DISCUSSION

In a previous study, it was postulated that upon the eccentric lateral loading, the abutment had been twisted within or over the play at the implant-abutment interface. This would provide firm engagement at the hexagon interface and disperse the lateral forces through the hexagon corners.[9] In the same study, secondary electron microscopy examination supported that tightening torque to 32 Ncm could not completely resist external torque forces. The amount of rotation due to eccentric loading might be dependent on the abutment rotational freedom within the play of the hexagon and the frictional forces that are built at the mating surfaces by tightening. The outcome of this loading effect was a rotation of the abutment internal hexagon against the implant counterpart until engagement.[9] The present study confirmed that conclusion by the presence of the statistically high significant difference in RD between groups A and B when compared with group C or D ($p < .001$). Nevertheless, a recent study[11] indicated that the orientation of the abutment hexagon to the implant counterpart after tightening related more to the initial positioning of the abutment by the operator than the tightening effect.

TABLE 3 All Pairwise Multiple Comparison Procedures Comparing Data of Test Groups Using Tukey Test

Group Comparison	Difference of Means	*p*	$p < .050$
D vs A	52.200	<.001	Yes
D vs B	51.600	<.001	Yes
D vs C	3.600	.011	Yes
C vs A	48.600	<.001	Yes
C vs B	48.000	<.001	Yes
B vs A	0.600	.929	No

The RD values of group C specimens revealed a statistically significant difference from those of group D ($p = .011$). Marked burnishing at the implant external hexagon corner that was demonstrated in a previous study would be increased with considerably greater number of eccentric loading cycles.[9] The torsion effect of the eccentric lateral cyclic loading would lead to the rotation of the abutment over the implant and engagement of the assembly hexagon components. Therefore, a longer time of loading should result in more deterioration of the joint and, consequently, more RD.

On the other hand, the presence of the play at the implant–abutment hexagon interface might be the cause of the resultant RD upon centric lateral loading in both loading periods for groups A and B. Upon centric loading, the loading time did not show a statistically significant difference in RD values although of the presence of a higher mean for group B that was loaded as twice the number of cycles as group A. Moreover, this would be related to the load centric direction with least torsion effect. The absence of misfit at the implant-abutment interface should lead to intimate engagement of joint components, and therefore, load dissipation through the external hexagon in the clamped components as compressive stresses.[6]

In an evaluation of machining accuracy and consistency, Binon[8] reported that the implant–abutment hexagon fit is important in single-tooth restorations "where exact seating is critical to attaining repeatable interproximal contacts and optimal anti-rotational characteristics." The machining tolerance of the present technology was described to reach 3–5 µm tolerances with computer numerically controlled screw machines.[1]

However, the tungsten carbide cutting tool can dull and must be replaced. Therefore, tolerances of the machined components will decrease in accuracy, if the tool is not replaced.

In the present study, the number of specimens used for each group might be relatively small. A greater number of specimens and testing other types of implant/abutment joint designs from different manufacturers might be applied in future investigations.

CONCLUSIONS

Within the limitations of this in vitro study, the RD of the external hexagon joint components occurred significantly under eccentric lateral loading when compared to centric loading. Furthermore, displacement increased considerably with a longer period of eccentric lateral loading but not with centric.

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