Stability of Implant-Abutment Interface with a Hexagon-Mediated Butt Joint: Failure Mode and Bending Resistance

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ABSTRACT

Background: Clinical data showed that the external hexagon implant system with a gold abutment screw has reduced the problem of screw loosening or fracture. However, the behavior of the implant-abutment joint components with respect to unfavorable bending force is still unclear.

Purpose: This study investigated the joint instability and bending resistance of a single-tooth external hexagon implant system after lateral cyclic loading.

Materials and Methods: Fifteen implant assemblies (Nobel Biocare, Göteborg, Sweden) were divided equally into three groups: A, B, and C. Each assembly consisted of a Brånemark System® Mk IV implant (4 × 10 mm) mounted in a brass block, a CeraOne® abutment (3 mm), and an experimental cement-retained superstructure. For group A, a centric lateral cyclic load of 50 N was applied for 1.0×10^6, whereas for group B, the same load was eccentrically applied for 1.0×10^6 cycles. Group C, the control, was not loaded. After cyclic loading, specimens were mounted in a universal testing machine, and the yield and bending strengths were measured (kg). The external hexagon surface texture was examined using a secondary electron microscope. The data were analyzed with one-way analysis of variance and compared by the Tukey test ($\alpha = .05$).

Results: For all test specimens, the abutment screw was plastically bent in the unthreaded portion. Group B had a significantly lower mean yield and bending strengths than group C ($p = .005$ and .010, respectively). Post–cyclic loading photographs showed that group B implants had marked burnishing around the hexagon corners. The bending force abraded both corner areas of the hexagon surface but left the middle area nearly intact for all tested groups. However, group B had the significantly lowest mean abraded area.

Conclusion: Within the limits of this study, eccentric rather than centric lateral cyclic loading negatively affected the resistance of the implant-abutment joint to static bending.

KEY WORDS: abutment screw, bending strength, external hexagon implant, implant-abutment interface, lateral cyclic loading, screw loosening, yielding strength

A commonly reported mechanical problem that affects single-tooth implant replacements is screw joint instability, specifically, loosening or fracture of the abutment screws.[1–5] One hundred seven single-tooth restorations supported by implants (Nobel Biocare AB, Göteborg, Sweden) were followed prospectively for 5 years.[3–5] It was reported that 26% of the abutment screws were retightened during the first year. During the third year of observation, 11% loosened in 10 patients. Moreover, one titanium abutment screw fractured after 3 years and 13 screws were replaced by the new gold alloy screws between the third and fifth years. Another prospective study presented the results after 5 years of loading of 65 CeraOne® abutments (Nobel Biocare AB).[6] It was concluded that the CeraOne system eliminated the problem of screw loosening, and no complications were reported. These results were attributed to the lower amount of frictional forces produced between

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the titanium implant component and the gold alloy screw that replaced the titanium screw. Actually, the tensile and yield strengths are higher for the gold alloy than for titanium; thus, a higher preload can be generated in the gold alloy screw.[7] For the CeraOne gold alloy abutment screw, Jörnéus and colleagues reported the ultimate tensile and yield strengths of 1,450 and 1,370 N, respectively.[7] These values are more than twice those of the titanium grade 1 screw (630 and 470 N, respectively). Tan and Nicholls reported a mean screw joint preload of 643.4 N for the same gold alloy screw with recommended tightening torque of 32 Ncm.[8] This value was the highest preload recorded among the seven external hexagon abutment systems investigated. Conversely, four (4.1%) gold alloy abutment screws loosened in a recent 5-year multicenter study of 97 CeraOne single-tooth implants.[9] Considering the previously mentioned studies, the introduction of the new abutment screw in the CeraOne abutment had significantly decreased but did not eliminate screw loosening.[9]

Comparing the strength of seven implant systems under static cantilever bending, Möllersten and colleagues stated that implants with a deep implant-abutment joint, such as the internal conical connection, favor resistance to bending moments, in contrast to shallow joints, such as the hexagon-mediated butt joint.[10] The single-tooth implants with the EsthetiCone™ abutment system (Nobel Biocare AB) using a titanium abutment screw had the lowest failure force among seven different types of implant systems.

In a recent study, the fatigue resistance to a lateral cyclic load of 100 N of the 4 mm Nobel Biocare implant system with the hexagon-mediated butt joint was investigated.[11] All abutment screws fractured between 1.2×10^6 and 1.7×10^6 cycles, and all failures occurred at the junction between the unthreaded and threaded parts of the screw. Thus, it was hypothesized that the axial preload of the screw in the butt joint was the determining factor for the joint stability. The presence of play at the joint interface might allow micromovement of the abutment screw, leading to the increase in its tensile stress and thus to the decrease in its preload.[11,12]

Kaukinen and colleagues examined the influence of occlusal surface design on the longitudinal success of implant treatment.[13] It was indicated that the occlusal configuration and cusp angulation of implant-retained prostheses play a significant role in force transmission and the stress-strain relationship in bone. Another recent study investigated the influence of two patterns of lateral cyclic loading on the abutment screw loosening in a hexagon-mediated butt joint system.[14] As is explained later in the present 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 results indicated that the centric loading period significantly decreased the reverse torque, whereas the eccentric load was not significantly affected. These results might be related to the presence of misfit at the hexagon interface, which aggravated screw fatigue in the centric loading group. However, the eccentric lateral load engaged the implant hexagon with the abutment counterpart and supplied a lock effect, which dispersed bending forces away from the abutment screw and reserved the screw torque.[14]

Khraisat and colleagues investigated the effect of different cyclic loading periods on abutment screw loosening and bending resistance of a single-tooth external hexagon implant system.[15] It was determined that long-term fatigue considerably affected the reverse torque values under centric lateral load, whereas it had no significant effect on the resistance of the implant-abutment joint to static bending.

Multiple authors have discussed embedment relaxation as a major mechanism of screw loosening.[16,17] It might be defined as wear or flattening of the microscopic rough high spots at the contacting surfaces caused by the micromovements when the joint is subjected to external loads and vibrations. Occurrence of wear at the contact areas may bring the two surfaces closer to each other.[16,17]

The aim of this study was to investigate the joint instability and bending resistance of a single-tooth external hexagon implant system after lateral cyclic loading. Therefore, specimens were quasistatically bent after lateral cyclic loading, and then the yield and bending strengths were determined. Furthermore, the surface texture of the implant hexagon was compared between the three groups by secondary electron microscopic examination. It was hypothesized that the eccentricity of lateral cyclic loading does not affect the resistance of the implant-abutment joint to static bending force.

MATERIALS AND METHODS

In this study, 15 implant assemblies obtained from a previous study were used and each consisted of an implant (4 × 10 mm, Brånemark System® Mk IV, Nobel Biocare AB) mounted in a brass block, an abutment (3 mm, CeraOne), and an experimental cement-retained casting (7 × 10 × 7 mm). Specimen preparation, casting fabrication, and cementation were described in the previous studies.[14,15] In one study, to investigate the influence of lateral cyclic load on the reverse torque of abutment screw, specimens were divided into three groups, and each implant assembly was held in place by a bench vice attached to a solid board for initial reverse torque.[14] A torque gauge (Model BTG60CN, Tonichi MFG. Co., Tokyo, Japan) was used to ensure an accurate application of reproducible force to each abutment screw.[14–17] Ten minutes later, after the initial tightening to an optimum torque of 32 Ncm, the screw was retightened to the same torque to minimize embedment relaxation between the mating threads.[14–17] Five minutes later, the preload reverse torque was measured using the same torque gauge and recorded. Subsequently, the screw was tightened and then retightened as described previously. After that, specimens were subjected to a 50 N lateral cyclic loading. In group A, the load was applied perpendicular to the implant long axis (0 mm off axis) at 11.5 mm from the brass block surface for 1×10^6 cycles. For group B, the load was applied eccentrically distanced at 4 mm in a loosening direction (anticlockwise) for the same loading period as group A.[14] For group C, the control group, the specimens were left unloaded for the same loading time period as for groups A and B.

On completion of the dynamic test and measurement of the abutment screw reverse torque,[14] all specimens underwent preparation for the present study. The implant assembly was held in place by a bench vise attached to a solid board, and the abutment screw was tightened to 32 Ncm using a torque gauge as mentioned above.

Static Bending Test

Each specimen was fixed in a holder of a screw-driven universal testing machine (Instron AG 1000E, Shimadzu, Kyoto, Japan). Bending force perpendicular to the implant long axis was centrically (0 mm off axis) applied at 11.5 mm from the block surface at a crosshead speed of 1 mm/min (Figure 1). The force-deflection curve of the abutment-implant assembly was recorded on chart paper at a speed of 30 mm/min. The yield strength and corresponding deflection at the loading point were determined on the chart (Figure 2). Although the yield point is theoretically defined as the point at which the assembly component starts to deform plastically,[7] it is difficult to practically determine. In the present study, the yield point was expediently defined as the point at which the curve intersects with a line parallel to its straight part with a distance of 1 mm (see Figure 2). If the assembly was unloaded at this point, it could show a permanent deflection of 0.033 mm because the deflection was recorded on the chart with ×30 magnification.[15] The bending strength was determined as the peak value of the force-deflection curve. In this study, specimen preparation and testing were performed by the same operator and completed in random sequence to avoid potential errors owing to an increase in the operator's skill.

Scanning Electron Microscopy

Using an electron probe microanalyzer (EPMA-8705, Shimadzu), scanning electron microscopic examination was conducted to evaluate the degrees of burnishing and abrasion at the compressed interface of the implant hexagon. First, the area adjacent to the hexagon corner was compared before and after lateral cyclic loading, with a focus on the degree of burnishing that was evaluated visually by the operator. Moreover, the hexagon surface, including the middle zone, was examined after the static bending test, with a focus on the

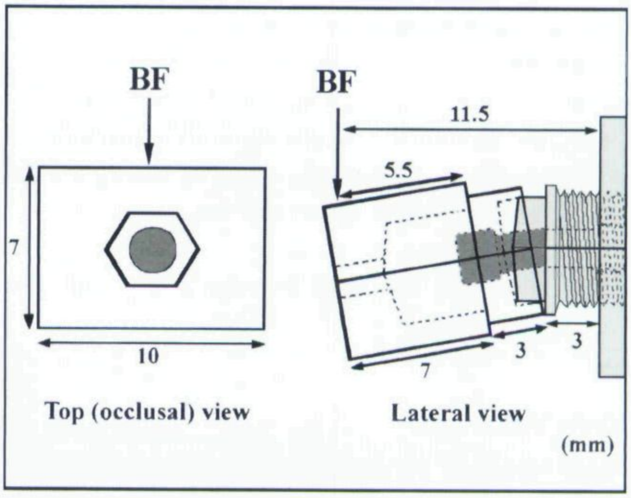

Figure 1 Schematic diagram of experiment design and loading condition. BF = bending force.

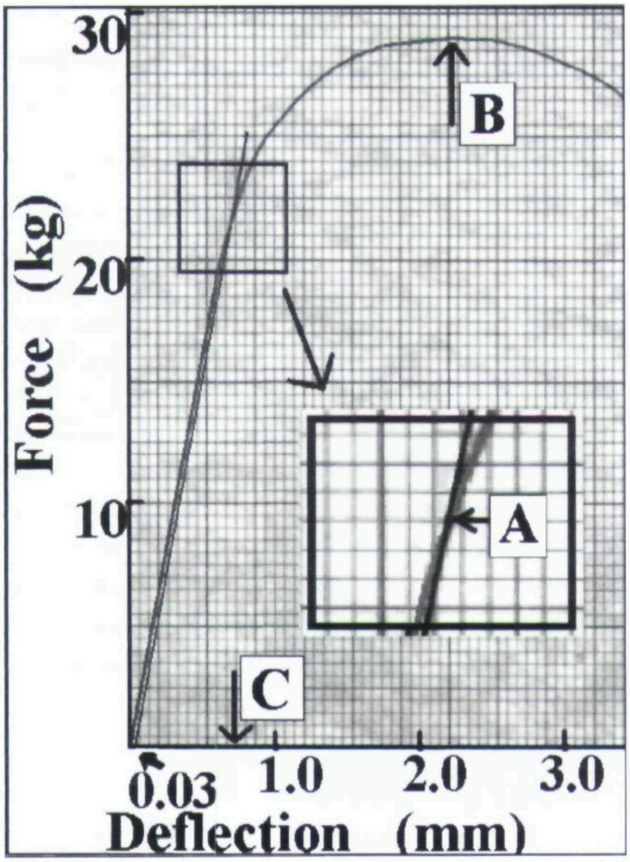

Figure 2 Force-deflection graph of a specimen showing an expediently defined yield point (A), bending strength (B), and deflection at yield point (C). The straight line was drawn parallel to the straight part of the curve, with the distance corresponding to a deflection of 0.033 mm.

degree of abrasion. The abraded area was traced on the scanning electron micrograph print and calculated as a percentage of the total examined area using computer software (*Hanako*, Just System Inc., Tokushima, Japan). Abrasion of less than 25% of the traced surface area was categorized as mild, whereas that from 25 to 50% was categorized as moderate and that over 50% as severe. The same magnification and orientation were applied for the compared surfaces by using the calibrated monitor of the microanalyzer.[14] The surface to be examined was marked beforehand by placing a small groove with a carbide round bur (no. 012; Dentsply-Maillefer, Ballaigues, Switzerland) on the implant neck so as to observe the same location before and after mechanical testing.

Statistical Analysis

Mean values of yielding strength, deflection at yield point, bending strength, hexagon abraded area, and the respective standard deviations and standard error of means were calculated. The data were then analyzed with one-way analysis of variance (ANOVA) ($\alpha = .05$). Accordingly, all pairwise multiple comparison procedures using the Tukey test ($p < .050$) were performed for the comparisons among individual means of the experimental groups.

RESULTS

For all test specimens, the abutment screw was plastically bent in the unthreaded part without fracture. No decementation was noticed by tactile or visual inspection on the completion of static loading. Values of yielding strength, deflection at yield point, and bending strength are shown in Table 1. Table 2 displays the calculated data for each of the three tested groups. Group C (the control) had the highest means in the three variables among the tested groups, whereas group B, which had undergone eccentric lateral cyclic loading, had the lowest yielding and bending strengths. For the yield and bending strengths, the null hypothesis was rejected because one-way ANOVA indicated that the differences in the mean value among the test

TABLE 1 Test Groups with the Yield Strength, Deflection at Yield Point, Bending Strength, and Hexagon Abraded Area

Specimen	YS (kg)	DYP (mm)	BS (kg)	HAA (%)
Group A				
1	24.75	1.20	30.05	40.92
2	21.50	0.70	29.47	52.32
3	22.50	0.67	31.55	44.83
4	22.75	0.83	32.15	60.10
5	25.75	0.80	32.72	44.03
Group B				
1	21.00	0.97	30.52	31.48
2	21.50	0.70	29.07	19.97
3	21.00	0.80	29.82	23.91
4	22.00	0.80	29.50	22.95
5	21.75	0.80	29.35	18.23
Group C				
1	23.75	1.05	30.10	31.89
2	24.30	0.82	32.77	69.52
3	24.00	0.87	31.92	49.41
4	25.00	1.37	33.10	59.64
5	27.50	1.77	33.57	38.20

BS = bending strength; DYP = deflection at yield point; HAA = hexagon abraded area; YS = yield strength.

TABLE 2 Means of Yield Strength, Deflection at Yield Point, Bending Strength, and Hexagon Abraded Area for the Experimental Groups

Group	*n*	Mean	SD	SEM
Yield strength (kg)				
A	5	23.450	1.745	0.780
B	5	21.450	0.447	0.200
C	5	24.910	1.522	0.681
Deflection at yield point (mm)				
A	5	0.840	0.212	0.0948
B	5	0.814	0.0974	0.0435
C	5	1.176	0.396	0.177
Bending strength (kg)				
A	5	31.188	1.383	0.618
B	5	29.652	0.556	0.248
C	5	32.292	1.365	0.611
Hexagon abraded area (%)				
A	5	48.440	7.747	3.464
B	5	23.308	5.104	2.283
C	5	49.732	15.339	6.860

SEM = standard error of the mean.

TABLE 3 One-Way Analysis of Variance ($p < .050$) for the Experimental Groups

Source of Variation	*df*	SS	MS	F Value	Probability
Yield strength					
Between groups	2	30.172	15.086	8.141	.006
Residual	12	22.237	1.853		
Total	14	52.409			
Deflection at yield point					
Between groups	2	0.408	0.204	2.897	.094*
Residual	12	0.844	0.0704		
Total	14	1.252			
Bending strength					
Between groups	2	17.580	8.790	6.454	.013
Residual	12	16.343	1.362		
Total	14	33.923			
Hexagon abraded area					
Between groups	2	2219.191	1109.595	10.359	.002
Residual	12	1285.402	107.117		
Total	14	3504.593			

df = degree of freedom; MS = mean square; SS = sum of squares.
*Not significant at $\alpha < .05$.

groups were greater than would be expected by chance ($p < .050$) (Table 3). For the deflection at yield point, there was no statistically significant difference ($p > .050$); thus, the null hypothesis was accepted. The results of the Tukey test indicated that group B had significantly lower mean yield and bending strengths than group C ($p = .005$ and .010, respectively).

For the hexagon surface texture, comparison was made between the pre– and post–cyclic loading photographs. With group B implants, marked burnishing was observed around the hexagon corners, particularly on the surfaces that underwent compression owing to the abutment rotation against the implant hexagon (Figure 3).[14] This change was insignificant for group A, which had undergone centric lateral cyclic loading.

For the implant hexagon surface that underwent compression owing to the static bending, both corner areas of the hexagon surface were most abraded, whereas the middle surface was least affected (Figure 4). This phenomenon was primarily noticed in groups A and C (high moderate), whereas it was mild in group B, as was evaluated by the values of the abraded area (see Tables 1 and 2). Group C (the control) had the highest mean among the tested groups, whereas group B had the lowest value (see Table 2). For the abraded area, the one-way ANOVA proved that the differences in the mean value among the test groups were greater than would be expected by chance ($p < .050$) (see Table 3). The results of the Tukey test indicated that group B

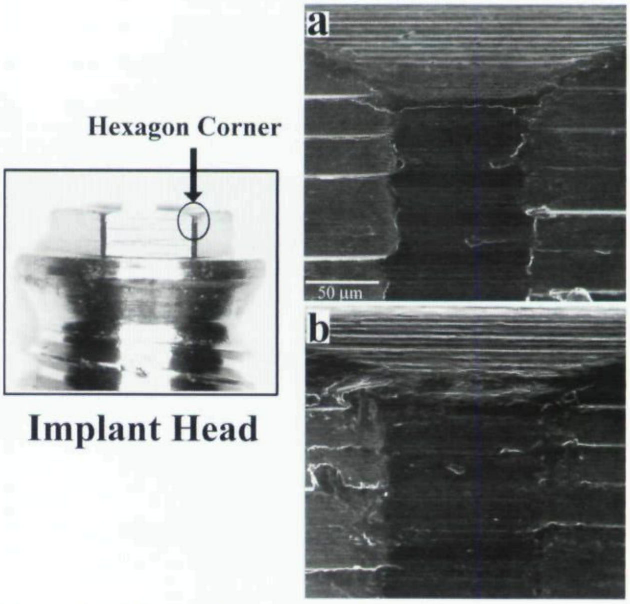

Figure 3 A close-up photograph (*left*) of an as-received implant and two scanning electron micrographs (*right*) of the hexagon corner of a group B specimen before (a) and after (b) eccentric lateral cyclic loading. The parallel horizontal lines are the machining marks left when the hexagon was manufactured.

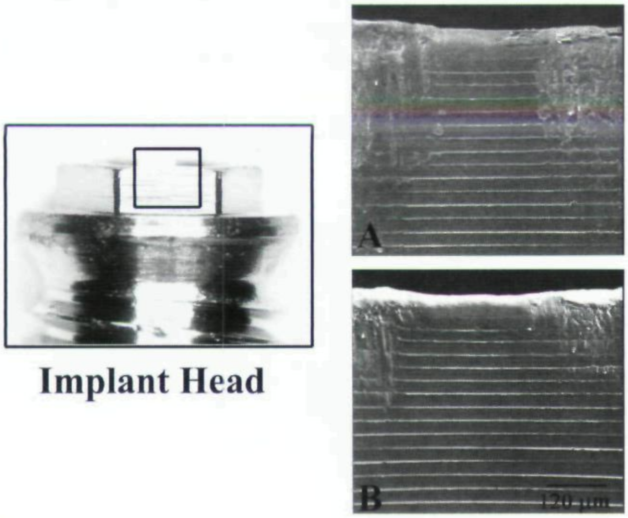

Figure 4 A close-up photograph (*left*) of an as-received implant and two scanning electron micrographs (*right*) of hexagon surfaces abraded during static bending: severe (A) and mild (B) from groups A and B, respectively. The *squared area* in the left-side photograph indicates the scanning electron micrograph section on the right.

had a significantly lower mean than groups C ($p = .004$) and A ($p = .006$) (Table 4).

DISCUSSION

Bending forces are antagonized mainly by the abutment screw, implant external hexagon, and implant-abutment interface platform. Although it was hypothesized that the eccentricity of lateral cyclic loading does not affect the resistance of the implant-abutment joint to static bending force, the results of the present study revealed that the means of yield and bending strengths for group B were the lowest compared with the other test groups (see Table 2). Significant differences were demonstrated when the yield and bending strength means of group B were compared with those of group C (see Table 4). However, scanning electron micrographs indicated that the static bending abraded both end-side areas of the hexagon surface but left the middle area nearly intact for all tested groups, which was evidenced by the remaining machining marks (see Figure 4). Nevertheless, group B had the significantly lowest mean of abraded area among the test groups (see Tables 2 and 4), in addition to the lowest means of yield and bending strengths. These results might signify that the hexagon interface contact occurred only in both corner areas of the hexagon surface, which played an important role in resisting bending and twisting forces applied to the abutment.

Furthermore, scanning electron micrographs indicated that the implant hexagon surface of group B had been burnished during resisting the torque originating from the eccentric lateral cyclic load, particularly in the end-side area (see Figure 3).[14] This burnishing may have deteriorated the fit at the hexagon interface and made the joint unstable. Therefore, the role of the hexagon end-side areas in resisting the bending force was reduced for group B specimens, the abutment screw had the major role in resisting the force, and, thus, earlier joint failure occurred (Figure 5, right).

The highest bending resistance of the implant-abutment joint was for group C, the control. This might be related to the intact joint components, primarily the implant hexagon and abutment screw (see Figure 5, left), which was not cyclically loaded.

TABLE 4 All Pairwise Multiple Comparison Procedures Using the Tukey Test

Group Comparison	Difference of Means	p	$p < .050$
Yield strength			
C vs A	1.460	.247	No
C vs B	3.460	.005	Yes
A vs B	2.000	.091	No
Bending strength			
C vs A	1.104	.327	No
C vs B	2.640	.010	Yes
A vs B	1.536	.136	No
Hexagon abraded area			
C vs A	1.292	.979	No
C vs B	26.424	.004	Yes
A vs B	25.132	.006	Yes

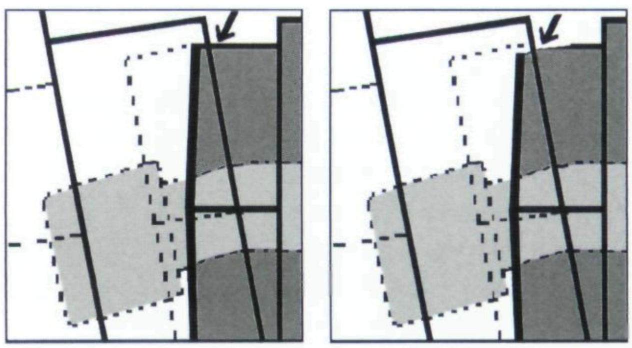

Figure 5 Schematic illustrations showing the resistance of the implant hexagon to static bending force. *Left* (groups A and C), the relatively intact surface (*arrow*) was more resistant; *right* (group B), the partially burnished surface (*arrow*) was less resistant.

Although group C, the control, had a higher mean of yield and bending strengths compared with group A, statistical analysis revealed no significant difference. A larger number of specimens may clarify the presence of significant differences in future research.

Although group C had the highest mean deflection at yield point, statistical analysis revealed no significant difference between the tested groups. If the linear portion of the deflection curve sloped identically in all specimens, the value of deflection at yield point should vary with that of yielding strength; thus, a significant difference might be found at least between groups B and C. These unexpected results might be related to the machining accuracy variation over a considerably wide range of specimens of the same commercial product.[14] In addition, rotational misfit at the implant-abutment hexagon interface has been considered a key factor in screw joint failure.[18] A direct correlation between the implant-abutment rotational misfit and screw loosening was indicated in the literature.[18] Therefore, the misfit at the hexagon interface would influence the initial deflection behavior of the assembly. Therefore, a larger number of specimens might produce a significant difference.

The CeraOne implant system in group C had about two times higher structural strength than the EsthetiCone tested by Möllersten and colleagues,[10] despite the fact that both systems used abutment screws of the same diameter (2 mm) and that the distance between the loading and supporting points in this study (11.5 mm) was about twice that of their findings (6 mm) (see Figure 1). In their study, specimens were not loaded before the bending test. Of the 10 specimens, 9 abutment screws were plastically bent in the unthreaded portion and 1 fractured in the threaded portion.[10] In the present study, the 15 tested abutment screws were plastically bent in the unthreaded portion. The higher ultimate tensile and yield strengths of the CeraOne gold alloy abutment screw compared with the EsthetiCone titanium screw may be the primary reason for this difference.[7]

In spite of the presence of rotational misfit at the hexagon-mediated butt joint, the implant under the eccentric lateral cyclic load was able to reserve the highest abutment screw torque, probably because of the joint stability owing to the torque-induced engagement at the end-side area of the hexagon interface.[14] In contrast, the implant under the centric lateral cyclic load showed a significant reduction in the screw torque. Probably the misfit at the butt joint would partially void the role of the implant hexagon in resisting lateral forces, leading to repeated bending, loosening,[14] and, finally, fatigue failure[11] of the abutment screw. However, the present results indicated that the eccentric lateral cyclic force gradually damaged the contact area (burnishing) and deteriorated the joint fit, which also decreased the resistance of the joint to the static bending force. These results imply the possibility that a multiplier effect of centric and eccentric lateral cyclic forces in the intraoral environment would lead to the loosening and eventual fatigue failure of the abutment screw earlier than would be expected from the sole effect of centric lateral force. Therefore, proper alignment of the implant, so that the occlusal loads are directed alongside the longitudinal axis of the implant, and occlusal adjustment by narrowing the restoration width and flattening cuspal inclination may be used to avoid bending moments caused by the lateral component of occlusal forces.[13]

CONCLUSION

Within the limitations of this study, it was concluded that eccentric lateral cyclic force gradually burnished the contact area at the implant-abutment hexagon interface and deteriorated the joint fitness, which significantly decreased the resistance of the joint to bending forces.

REFERENCES

1. Jemt T, Lekholm U, Grondahl K. 3-year follow up study of early single implant restorations ad modum Brånemark. Int J Periodontics Restorative Dent 1990; 10:340–349.
2. Jemt T, Pettersson P. A 3-year follow-up study on single implant treatment. J Dent 1993; 21:203–208.
3. Jemt T, Laney WR, Harris D, et al. Osseointegrated implants for single tooth replacement: a 1-year report from a multicenter prospective study. Int J Oral Maxillofac Implant 1991; 6:29–36.
4. Laney WR, Jemt T, Harris D, et al. Osseointegrated implants for single-tooth replacement: progress report from a multicenter prospective study after 3 years. Int J Oral Maxillofac Implants 1994; 9:49–54.
5. Henry PJ, Laney WR, Jemt T, et al. Osseointegrated implants for single-tooth replacement: a prospective 5-year multicenter study. Int J Oral Maxillofac Implants 1996; 11:450–455.
6. Andersson B, Odman P, Lindvall AM, Branemark PI. Cemented single crowns on osseointegrated implants after 5 years: results from a prospective study on CeraOne. Int J Prosthodont 1998; 11:212–218.
7. Jörnéus L, Jemt T, Carlsson L. Loads and design of screw

joints for single crowns supported by osseointegrated implants. Int J Oral Maxillofac Implant 1992; 7:353–359.

8. Tan KB, Nicholls JI. Implant-abutment screw joint preload of 7 hex-top abutment systems. Int J Oral Maxillofac Implant 2001; 16:367–377.
9. Scheller H, Urgell JP, Kultje C, et al. A 5-year multicenter study on implant-supported single crown restorations. Int J Oral Maxillofac Implants 1998; 13:212–218.
10. Möllersten L, Lockowandt P, Lindén LA. Comparison of strength and failure mode of seven implant systems: an in vitro test. J Prosthet Dent 1997; 78:582–591.
11. Khraisat A, Stegaroiu R, Nomura S, Miyakawa O. Fatigue resistance of two implant/abutment joint designs. J Prosthet Dent 2002; 88:604–610.
12. Merz BR, Hunenbart S, Belser UC. Mechanics of the implant-abutment connection: an 8-degree taper compared to a butt joint connection. Int J Oral Maxillofac Implants 2000; 15:519–526.
13. Kaukinen JA, Edge MJ, Lang BR. The influence of occlusal design on simulated masticatory forces transferred to implant-retained prostheses and supporting bone. J Prosthet Dent 1996; 76:50–55.
14. Khraisat A, Hashimoto A, Nomura S, Miyakawa O. The effect of lateral cyclic loading on abutment screw loosening of external hex implant system. J Prosthet Dent 2004; 91: 326–334.
15. Khraisat A, Abu-Hammad O, Dar-Odeh N, Al-Kayed AM. Abutment screw loosening and bending resistance of external hexagon implant system after lateral cyclic loading. Clin Implant Dent Relat Res 2004; 6:157–164.
16. Dixon DL, Breeding LC, Sadler JP, McKay M. Comparison of screw loosening, rotation, and deflection among three implant designs. J Prosthet Dent 1995; 74:270–278.
17. Breeding LC, Dixon DL, Nelson EW, Tietge JD. Torque required to loosen single-tooth implant abutment screws before and after simulated function. Int J Prosthodont 1993; 6:435–439.
18. Binon PP, McHugh MJ. The effect of eliminating implant/abutment rotational misfit on screw joint stability. Int J Prosthodont 1996; 9:511–519.

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