Influence of eccentric cyclic loading on implant components: Comparison between external joint system and internal joint system

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The purpose of this in vitro study was to investigate the influence of eccentric loading on implant components by measuring screw loosening and observing these components under several load positions and magnitudes. The external and internal joint system implants with butt joint connection were subjected to cyclic loading tests according to the specifications of ISO 14801. Load position was set at 0, 4, or 8 mm, and load was set at 100 or 300 N. On the external joint system, the reverse torque values decreased with distal shift in the loading position and an increase in magnitude of load, and abrasion and deformation on the anti-rotation device were observed. On the internal joint system, no large decrease in reverse torque was observed even though increasing the load position and load, however, abrasion and deformation on the anti-rotation device as well as fracture at implant/abutment connection were observed.

Keywords: Titanium, Implant abutment, Eccentric moment, Fatigue test

INTRODUCTION

Implant restorations are widely recognized as a standard treatment with high survival rates and predictable long-term success. Long-term follow-up of large numbers of cases, however, has revealed various complications with such procedures1,2, and these can be classified as implant loss, surgical complications, marginal bone loss and peri-implant soft tissue complications, as well as mechanical and esthetic complications.

Mechanical complications have been reported to include screw loosening or fracture, veneering material fracture, and problems with retention of overdentures3,4, and all are commonly encountered in a clinical setting. In a review of the literature spanning 1981 through 2001, the incidence of abutment screw loosening was reported to be 6%5. Meanwhile, another study involving observation over a 15-year period showed that the incidence of abutment screw loosening was 32% in screw-retained and 9% in cement-retained restorations5. In a systematic review of 5-year survival in implant-supported single crowns and the incidence of biological and technical complications, Jung et al.6 investigated the influence of eccentric loading by using fatigue tests and dynamic cyclic loading to simulate masticatory forces. Khraisat et al.14 investigated the influence of lateral cyclic loading on abutment screw loosening in an external hexagon implant system. They found that reverse torque values were better preserved under eccentric lateral than under centric lateral loading. Tsuge and Hagiwara8 evaluated the influences of eccentric cyclic loading on abutment screw loosening in internal and external hexagon implant systems with two different screw materials. They reported that the reverse torque values after cyclic loading test were significantly greater than the initial reverse torque values. In an investigation on how direction of twisting affected abutment screws, Yao et al.15 reported that direction had little influence on total torque loss in an internal hexagon connection implant system.

Thus, a consensus has not yet reached on the influence of eccentric loading on screw loosening. This may be because few investigations have evaluated the influence of eccentric loading on implant components from the point of view of load position and magnitude.
Therefore, the purpose of this in vitro study was to investigate the influence of eccentric loading on implant components by measuring screw loosening and observing these components under several load positions and magnitudes.

**MATERIALS AND METHODS**

**Sample preparation**

Figure 1 shows the external and internal joint system implants (φ 4.4×12 mm, GC implant Re, GC, Tokyo, Japan) with butt joint connection used in this study. In this study, cp-Ti (grade 2) was used for implant body and abutment of external joint system, cp-Ti (grade 4) was used for implant body and abutment of internal joint system, and titanium alloy (Ti-6Al-4V) was used for abutment screw for both systems, respectively. The external joint system has a hexagonal connection and the internal joint system has a trilobe one. A total of 18 implant assemblies were prepared for each system, respectively.

Each implant assembly consisted of an external or internal joint system implant together with its respective prefabricated abutment, abutment screw, and experimental superstructure (Fig. 2). The experimental superstructures were made by CAD/CAM (M32-V, CITIZEN MACHINERY, Nagano, Japan). The load positions were set at 0, 4, or 8 mm from the supraimplant position (0 mm) (Fig. 2B). This in vitro study assumed single-tooth implant restorations, and the configuration of experimental superstructure was referred to previous studies. It was also supposed that twisting moment was generated by the eccentric loading. Moreover the load position of 8 mm was set to generate the maximum twisting moment that can occur in clinical situation by implant displacement.

**Recording reverse torque value before cyclic loading test**

A digital torque meter (BTG50CN, Tohnichi, Tokyo, Japan) with a reading accuracy of 0.05 N • cm/digit was used to measure reverse torque (Fig. 3). Reverse torque was recorded as follows: first, the tip of a screw driver (MACHINE SKILL-DRIVER, GC) was mounted in the 3-jaw chuck of the torque meter; next, the abutment screw was tightened to 30 N • cm (external joint system).
or 20 N·cm (internal joint system), as recommended by the manufacturer for clinical applications; 10 min later, the abutment screw was retightened to the same torque to minimize the influence of settling; finally, the reverse torque value before cyclic loading test was measured again 5 min later. The abutment screw was then retightened to the same torque as that recommended by the manufacture for the cyclic loading test.

**Cyclic loading test**
The cyclic loading test was carried out according to the specifications of ISO 14801. Each implant assembly, including the implant body, abutment and abutment screw, was fixed in a specimen holder at an angle of 30° to the vertical axis, and the experimental superstructure was fixed to abutment using a side screw (Fig. 2A). Testing was performed using a servo-driven load cell type testing machine (TY-100, Techno Ark, Nagano, Japan), applying cyclic load at a frequency of 2 Hz for 10⁶ cycles in room atmosphere (Fig. 4). It was confirmed that no loosening was recognized at the side screw during cyclic loading test. Table 1 shows the implant systems and loading conditions used. Load position was set at 0, 4, or 8 mm, and load was set at 100 or 300 N (Fig. 2B).

**Recording the reverse torque value after cyclic loading test**
After 10⁶ cycles of cyclic loading, the implant assembly was removed from the testing machine and specimen holder, and the reverse torque value after cyclic loading test was determined after removing the experimental superstructure.

**Scanning electron microscopy (SEM)**
The anti-rotation device of the implant body and abutment after cyclic loading were observed using a scanning electron microscopy (SEM; SU6600, Hitachi, Tokyo, Japan).

**Micro-computed tomography (μ-CT)**
Before and after cyclic loading, micro-computed tomography (μ-CT) images of the anti-rotation device of the external or internal joint system were acquired (HMX-225 Actis4, Tesco, Miyagi, Japan) under the following imaging conditions: tube voltage, 180 kV; tube current, 146 μA. Three-dimensional (3D) structure analysis software (TRI/3D/BON, RATOC System Engineering, Tokyo, Japan) was used to create a 3D reconstruction, and the internal structure was observed. In addition the degree of deformation was measured at the width of the sleeve in the internal joint system. The width of the sleeve, which was defined as the distance between the corners of each sleeve on the anti-rotation device, was measured on the implant body side. The value obtained was then taken as indicating the degree of deformation of the anti-rotation device (Fig. 5).

**RESULTS**

**Reverse torque value**
1. External joint system
The two-way ANOVA revealed that, loading position, load, or interaction significantly influenced the reverse torque value after cyclic loading test (Table 2).

The reverse torque value before cyclic loading test was 24.30 (±1.08) N·cm, and Fig. 6 shows the reverse torque values after cyclic loading test. With a load of 100 N, no statistically significant difference in the reverse torque was observed among load positions. With a load of 300 N, the reverse torque showed a decrease with increase in load position. At a loading position of 4 or 8 mm, the reverse torque under a load of 300 N was
significantly lower than that under 100 N.

2. Internal joint system
Fracture was observed in one of the assemblies at the implant/abutment connection after loading under 300 N at loading position 8 mm, while on another assembly the abutment could not be removed from the implant body.

The two-way ANOVA revealed that only load significantly influenced the reverse torque value after cyclic loading test (Table 3).

The reverse torque value before cyclic loading test was 17.29 (±0.34) N•cm, and Fig. 7 shows the reverse

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**Table 2 Two-way ANOVA of reverse torque value after cyclic loading test for external joint system**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
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<td>91.0438</td>
<td>28.8192</td>
<td>0.0000 **</td>
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<tr>
<td>Load</td>
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<td>111.8509</td>
<td>111.8509</td>
<td>35.4056</td>
<td>0.0001 **</td>
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<tr>
<td>Position * Load</td>
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<td>18.4871</td>
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<td>0.0168 *</td>
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<tr>
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<td>—</td>
<td>—</td>
</tr>
<tr>
<td>total</td>
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<td>368.8223</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

**df:** Degree of freedom, **SS:** Sum of squares, **MS:** mean square.

**Significant at 1%, * Significant at 5%.

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**Fig. 6** Reverse torque values after cyclic loading test in external joint system (**: p<0.01, *: p<0.05, n=3). The reverse torque value before cyclic loading test was 24.30 (±1.08) N•cm.

**Fig. 7** Reverse torque values after cyclic loading test in internal joint system (**: p<0.01, *: p<0.05, n=3). The reverse torque value before cyclic loading test was 17.29 (±0.34) N•cm.

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**Table 3 Two-way ANOVA of reverse torque value after cyclic loading test for internal joint system**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F value</th>
<th>p</th>
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<tr>
<td>Load position</td>
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<td>0.3480</td>
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<td>0.2715</td>
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<tr>
<td>Load</td>
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<td>3.2821</td>
<td>3.2821</td>
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<td>0.0034 **</td>
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<tr>
<td>Position * Load</td>
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<td>0.5114</td>
<td>2.1621</td>
<td>0.1615</td>
</tr>
<tr>
<td>E</td>
<td>11</td>
<td>2.6017</td>
<td>0.2365</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>total</td>
<td>16</td>
<td>7.2394</td>
<td>—</td>
<td>—</td>
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</tr>
</tbody>
</table>

**df:** Degree of freedom, **SS:** Sum of squares, **MS:** mean square.

**Significant at 1%.
torque values after cyclic loading test. There are no large differences in the reverse torque among the load condition, despite the reverse torque under 300 N on both loading position were significantly lower than that under 100 N at a loading position of 4 mm.

Scanning electron microscopy
1. External joint system
Figures 8 and 9 show the anti-rotation device of the abutment and the implant body after cyclic loading, respectively. Marked abrasion and deformation were observed on the compression side of the anti-rotation device in both the abutment and implant body (arrows). Deformation was greatest under a load of 300 N and at a load position of 8 mm.

2. Internal joint system
The anti-rotation device of the abutment and the implant...
body after cyclic loading are shown in Figs. 10 and 11, respectively. Marked abrasion and deformation were also observed on the compression side of the anti-rotation device in both the abutment and implant body (arrows). Deformation was greatest under a load of 300 N and at a loading position of 8 mm.

**Micro-computed tomography of internal joint system**

Figure 12 shows an example of the μ-CT images of the anti-rotation device in each system before and after cyclic loading test. No apparent deformation was observed in external joint system after cyclic loading test. Meanwhile remarkable deformation was observed at the anti-rotation device in internal joint system.

The two-way ANOVA revealed that loading position, load, or their interaction significantly influenced the width of the sleeve (Table 4). Figure 13 shows the width of the sleeve of the anti-rotation device. The width of the

![Fig. 10 SEM of anti-rotation device of the abutment in internal joint system. White arrow show abrasion and deformation on the compression side of the anti-rotation device.](image1)

![Fig. 11 SEM of anti-rotation device of the implant body in internal joint system. White arrow show abrasion and deformation on the compression side of the anti-rotation device.](image2)
Fig. 12 Horizontal cross-sectional μ-CT image of the anti-rotation device. (A) External joint system before cyclic loading test, (B) External joint system after cyclic loading test, (C) Internal joint system before cyclic loading test, (D) Internal joint system after cyclic loading test.

Fig. 13 The width of the sleeve of the anti-rotation device (**: $p<0.01$, $n=9$).

Table 4 Two-way ANOVA of width of the sleeve in the anti-rotation device

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>$F$ value</th>
<th>$p$</th>
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<td>11,321.3771</td>
<td>78.4996</td>
<td>0.0000 **</td>
</tr>
<tr>
<td>Load</td>
<td>1</td>
<td>5,189.1004</td>
<td>5,189.1004</td>
<td>35.9799</td>
<td>0.0000 **</td>
</tr>
<tr>
<td>Position * Load</td>
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<td>13,609.6203</td>
<td>6,804.8102</td>
<td>47.1829</td>
<td>0.0000 **</td>
</tr>
<tr>
<td>E</td>
<td>48</td>
<td>6,922.6591</td>
<td>144.2221</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>total</td>
<td>53</td>
<td>48,364.1339</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

df: Degree of freedom, SS: Sum of squares, MS: mean square. ** Significant at 1%.

sleeve at a loading position of 8 mm and under a load of 300 N was significantly higher than that under the other conditions, showing maximum deformation of the anti-rotation device.

DISCUSSION

The purpose of this study was to evaluate the influence of eccentric loading on implant components by measuring screw loosening, observing those components under several load positions and magnitudes.

A cyclic loading test was performed to simulate oral mastication based on protocols established in earlier studies\(^8,14\). A cyclic loading test were performed for $10^6$ cycles, which has been reported to produce results commensurate with 40 months of actual use\(^16\). Two loads, 100 or 300 N, were set considering that the average maximal posterior occlusal force for a fixed prosthesis supported by an implant has been reported to be between 35 and 330 N\(^17\).

The experimental superstructure was fabricated
based on the fact that the mean width of the human first molar is approximately 11.5 mm. Load was applied at 4 or 8 mm from the suprail implant position (0 mm), assuming a mesiodistal shift toward the posterior partially edentulous segment.

Based on a previously reported method, the reverse torque values were first measured before cyclic loading and then compared with those obtained after loading, with the difference taken to indicate the degree of screw loosening. We believe, therefore, that this method can be considered valid.

**Influence of eccentric loading in external joint system**

The results in the present study showed that reverse torque values decreased with distal shift in the loading position and an increase in magnitude of load. On the SEM observations, abrasion and deformation on the compression side of the anti-rotation device in both the abutment and implant body were recognized. The possible explanation has been proposed as 2 factors of screw loosening that involve the bending overload, fatigue of implant component, wear or flattening at the contacting screw surfaces, and bending moment. Therefore, it can be assumed in the present study that cyclic loading with eccentric loading induced the component deformation, and caused marked abrasion and burnishing on the compression side of the anti-rotation device in both the abutment and implant body, resulting in a reduction in the reverse torque values.

In this study, no significant difference in the reverse torque value after cyclic loading test was observed among load positions under a load of 100 N. On the contrary, with a load of 300 N, the reverse torque value after cyclic loading test showed a decrease with increase in load position. These results suggested that no screw loosening will occur when the load is applied to the central axis of the implant (load position 0 mm; the ideal position) under the normal-ranged occlusal force. In the meanwhile, when the implant is placed in the distal position slightly far from the ideal position (load position 4 mm), little loosening will occur under the small occlusal force (100 N), but a certain amount of loosening will occur under the large occlusal force (300 N). In addition, when the implant is placed in the distal position far from the ideal position (load position 8 mm), a substantial loosening will occur under the both occlusal forces (100 and 300 N).

**Influence of eccentric loading in internal joint system**

In the present study, no large decrease in reverse torque was observed even though increasing the load position and load. However, SEM and μ-CT observation revealed that the marked abrasion and deformation were recognized on the anti-rotation device in both the abutment and implant body; in particular, load of 300 N and at loading position of 8 mm. In addition, fracture was also observed at the implant/abutment connection after loading in one assembly, and the abutment could not be removed from the implant body on another assembly. Figure 14 shows SEM of the fractured surface at implant/abutment connection in internal joint system under a load of 300 N and a load position of 8 mm. Left: implant body side, Right: abutment side.

This absence of a marked decrease may have been due to certain structural characteristics of the internal joint system: when it is of the butt joint type, the abutment is engaged deeply inside the implant body, and one study has reported that this type of abutment protects the screw by supporting the load, thus keeping it tighter. However, the fact of generating the marked abrasion and deformation of the anti-rotation device in this study indicate that the fracture may occur at the implant/abutment connection after deformation of the anti-rotation device under the heavy load condition including the high load as well as the large loading position. In fact, Chae et al. reported that the fracture of abutment or screw was more frequent in the internal joint system in the clinical situation.

**Clinical implications**

On the external joint system, it is able to evaluate the influence of eccentric cyclic loading on implant components by measuring the reverse torque value, and thus it is important to retighten the screw during maintenance in a clinical setting. Such retightening should be performed at each time point during the maintenance period, as the rate of decrease in reverse torque will vary depending on the individual, affected by oral environmental factors such as occlusal force and the condition of the implant.

On the internal joint system, it is at risk for occurrence of the fracture at implant/abutment connection even though screw loosening is hard to generate with increasing the eccentric loading, indicating that it is difficult to evaluate the influence of eccentric cyclic loading on implant components by only the measuring the reverse torque value. Therefore, great care should be taken in performing pre-treatment examinations, and it is important to avoid the designing of implant superstructure and the position of implant placement that generate heavy eccentric loading.
CONCLUSION

On the external joint system, the reverse torque values decreased with distal shift in the loading position and an increase in magnitude of load, and abrasion and deformation on the anti-rotation device were increased. On the internal joint system, no large decrease in reverse torque was observed even though increasing the load position and load, however, abrasion and deformation on the anti-rotation device as well as fracture at implant/abutment connection were observed.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES