Effect of Single Off-Axis Implant Placement on Abutment Screw Stability Under Lateral Loading

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Purpose: The aim of this study was to evaluate the effect of off-axis implant placement in relation to the prosthetic crown on abutment screw loosening under different directions of twisting moments. Materials and Methods: Twenty-one implant assemblies were divided equally into three groups (n = 7). Each assembly consisted of an internal-octagon implant measuring 4.1 × 12 mm (standard plus implants) with corresponding 5.5-mm synocta abutments (Straumann) mounted in an epoxy resin-glass fiber composite. Group A had a straight implant configuration in relation to the prosthetic crown and was subjected to clockwise twisting moment (control). The other two groups, B and C, with off-axis implant placement were subjected to clockwise and counterclockwise moments, respectively. A lateral load of 80 N was applied to the specimens for 1 × 10⁶ cycles at 90 degrees to the long axis of the implant. The loading point was 4 mm from the center of the implant in group A and 6 mm in groups B and C. The reverse torque value (RTV) of the abutment screw was measured before and after loading. Data were analyzed using a paired samples t test and one-way analysis of variance (ANOVA) at a significance level of α = .05. Results: An increase in postloading RTV was found relative to preloading RTV in all groups, but was only significant in group A (P < .05). The mean reverse torque difference (RTD) was higher in group A (3.17 ± 1.04 Ncm), followed by groups B (1.03 ± 1.41 Ncm) and C (0.43 ± 1.09 Ncm). A significant difference in RTD was noted between group A and the remaining groups (P < .05). However, no significant difference was found between groups B and C (P > .05). Conclusion: Placement of an implant in an off-axis relation to the prosthetic crown resulted in significantly lower reverse torque values compared with straight implant configuration. However, the extent of reduction in Ncm is small and is considered clinically insignificant in the studied implant system. Furthermore, no significant difference was found in RTV between clockwise and counterclockwise twisting moments. Int J Oral Maxillofac Implants 2016;31:520–526. doi: 10.11607/jomi.4124

Keywords: implant cantilevers, lateral loading, off-axial loading, screw loosening

The high success rates and long-term follow-up results of osseointegrated dental implants have demonstrated that implants are a viable treatment option for edentulous patients as well as for patients with a single missing tooth.1–4

Abutment screw loosening is considered to be one of the most common complications associated with implant-supported prostheses and is an inconvenience for both the patient and the dentist.5,6 A recent report assessed the 5-year survival and complication rates of implant-supported single crowns, demonstrating that the incidence of screw loosening was 8.8%.7 Another systematic review compared the survival and complication rates of implant-supported prostheses that were reported in studies published before and after the year 2000. The rate of abutment screw loosening was reduced from 24.4% to 5.6% for implant-supported single crowns. However, they reported that the incidence of complications is still high, and their etiology should be identified for a more predictable treatment outcome.8 Abutment screw loosening is associated with screw-retained and cement-retained restorations. However, the accessibility of these screws is difficult in cement-retained prostheses, and the retrievability of the crowns in order to tighten a loose abutment screw is still unpredictable.9

One of the most common causes of abutment screw loosening is masticatory forces, which introduce complex stresses on the implant-abutment joint.10–12 Implant restorations are subjected to regular chewing patterns with combined horizontal and vertical forces; these forces are converted to bending and twisting.
moments with reversed direction in the oral cavity. A general assessment of the load likely to be placed on the implants should be performed when planning to restore the dentition with an implant-supported prosthesis. Detrimental forces, including excursive, off-axis, centric, and cantilever contacts, should be eliminated whenever possible.

The biomechanical behavior of dental implants is influenced by many factors, including the use of wide-diameter implants, narrow occlusal tables, and correct positioning of the dental implants.

In single-tooth implants, unless the load is centered and directed parallel to the long axis of the implant, a bending moment will always be present. Providing an axial alignment of the implant linear to the prosthetic component places less stress on the overall implant system, which leads to a decreased risk of screw loosening and fatigue fractures of the implants or their related components. However, due to anatomical limitations, implants may be placed in a less-than-ideal position. This situation may require extending the contours of the implant prosthesis horizontally. Mesial or distal cantilever and bucco- or linguo-occlusal extention in relation to the implant position increases the stress surrounding dental implants. A recent retrospective study reported more prosthetic complications in single implants with cantilevers replacing a missing maxillary and mandibular molar compared with restoration without cantilevers. According to Lee et al, a radiographic evaluation of the influence of the crown-implant width ratio on crestal bone loss around single implants after 1 year of loading showed that off-axial loading that was generated from the discrepancy between the crown and implant width did not increase the risk for peri-implant marginal bone loss. On the other hand, Rungsiyakull et al found that reducing the cusp inclination and occlusal table dimension reduced the bone strain around the implant, and the occlusal table dimension had a more important role than cusp inclination. Several studies emphasized the importance of the use of a wider-diameter implant or two standard splinted implants to replace a missing molar. However, limitations such as insufficient mesiodistal space and inadequate buccolingual bone dimension may interfere with this treatment.

A paucity of information exists in the literature on the biomechanical influence of different directions of twisting moments and off-axis implant placement on abutment screw stability of implant-supported single crowns. The null hypothesis was the following: the placement of an implant in an off-axis relation to the prosthetic crown (while subjecting it to clockwise and counterclockwise twisting moments) has no effect on abutment screw loosening.

MATERIALS AND METHODS

Implant Assembly Specimens

Twenty-one implant assemblies were divided randomly into three equal groups (n = 7). Each assembly consisted of an internal-octagon implant measuring 4.1 × 12 mm (standard plus implants [ITI system, Straumann]) with corresponding 5.5-mm synocta screw-retained abutments (048.605 ITI system, Straumann). The implants were mounted in an epoxy resin-glass fiber composite (NEMA Grade G-10 rod, Piedmont Plastics; modulus of elasticity: approximately 20 GPa) using a dental surveyor, leaving approximately 2 mm of rough surface exposed. The manufacturer provided Ti alloy abutment screws, which were used to attach the abutments to the implants.

Fabrication of the Superstructure

Two autopolymerizing acrylic resin (Duralay, Reliance Dental MFG) patterns were prepared to construct the superstructures (7 × 10 × 7 mm). Group A consisted of a straight configuration of the axis of the implant in relation to the axis of the supported prosthetic unit. Groups B and C consisted of off-axis implants in relation to the superstructure resembling an extended occlusal table. Groups B and C had the same design but were subjected to clockwise and counterclockwise loads, respectively. The abutment screw access opening was prepared in each acrylic resin pattern. Two molds were prepared using a silicone paste (Rema sil, Precision duplicating silicone, Dentaurum Gruppe) to standardize the fabrication of the two different designs of superstructures. The superstructures were cast using a base metal alloy (Kera NH, Ni 58, 40%, Cr 26, 91%; Figs 1 and 2). Before cementation, the abutment screw access opening was covered with vinyl-polysiloxane impression material (Virtual, refill light body, regular set wash material, Ivoclar Vivadent) to prevent the excess of cement from infiltrating the screw access hole. Twenty-four hours after testing, each superstructure was cemented using zinc phosphate cement (Henry Schein) according to the manufacturer’s instructions.

Placing the Abutment and Recording the Preloading Reverse Torque Value

The method of measuring the preload was based on the method reported by Khraisat et al.27 The effect of lateral loading was evaluated by examining the changes in reverse torque value (RTV). The screws were tightened to the recommended torque (35 Ncm) using a digital torque gauge (BTGE); the screw was then retightened (to the same torque value) 10 minutes later to minimize embedment relaxation between the mating threads. The RTV was measured after 5 minutes. After recording the preloading RTV, the screw was retightened to
35 Ncm (and again 10 minutes later using the same torque gauge). All measurements were performed by a single operator (A.A.).

Each specimen was horizontally secured and mounted in the holding vice of a cyclic loading universal testing machine (Instron, Model 3000 Plus Dynamic Testing System, Instron). A customized, self-aligning testing assembly was used to stabilize the specimen (Fig 3).

A lateral load of 0 to 80 N, with a frequency of 5 Hz, was applied perpendicularly and eccentric to the superstructure at a longitudinal distance of 9.5 mm from the block surface to the specimens. This action lasted for $1 \times 10^6$ cycles. The load was directed 4 mm from the center of the implant in group A and 6 mm from the implant in groups B and C (Fig 4). Group A was subjected to a clockwise twisting moment (control), while groups B and C were subjected to clockwise and counterclockwise twisting moments, respectively. Forty-eight hours after completing the loading cycles, the postloading RTV for the abutment screw of the implant assemblies was measured.

The data were analyzed using SPSS (version 16.0). A paired sample t test was used to compare the changes in RTVs prior to and following cyclic loading within each group. One-way analysis of variance (ANOVA) was used to examine the effects of off-axis implant placement on abutment screw loosening under clockwise and counterclockwise lateral loading.
Fig 4  Schematic drawings of the loading conditions: (a) straight configuration, (b) off-axis configuration, (c) lateral view.

Table 1  Mean, SD, and Standard Error Mean of Preloading and Postloading RTV

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Mean ± SD</th>
<th>Standard error mean</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>Preloading 7</td>
<td>30.96 ± 0.93</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Postloading 7</td>
<td>34.13 ± 0.86</td>
<td>0.32</td>
</tr>
<tr>
<td>B</td>
<td>Preloading 7</td>
<td>31.76 ± 0.84</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>Postloading 7</td>
<td>32.79 ± 0.82</td>
<td>0.31</td>
</tr>
<tr>
<td>C</td>
<td>Preloading 7</td>
<td>31.81 ± 0.93</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Postloading 7</td>
<td>32.25 ± 1.55</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Fig 5  The mean RTVs in all groups.

Table 2  Reverse Torque Difference in All Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Samples</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>2.15</td>
<td>4.05</td>
<td>3.05</td>
<td>2.75</td>
<td>2.45</td>
<td>5.10</td>
<td>2.65</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>-0.55</td>
<td>0.50</td>
<td>1.95</td>
<td>-0.70</td>
<td>2.50</td>
<td>2.80</td>
<td>0.75</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>-1.20</td>
<td>-0.80</td>
<td>1.95</td>
<td>0.55</td>
<td>0.65</td>
<td>0.95</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Fig 6  The mean RTDs in all groups.
RESULTS

The postloading RTV was higher than the preloading values in all of the groups, with the exception of two samples in groups B and C. The mean, standard deviation (SD), and standard error of the preloading and postloading values are given in Table 1.

The mean of the postloading RTV was highest in group A (34.13 ± 0.86) followed by groups B (32.79 ± 0.82) and C (32.25 ± 1.55; Fig 5).

The reverse torque value difference (RTD) was calculated by subtraction of preloading RTV from the postloading RTV (Table 2). The mean RTD in group A was the highest (3.17 ± 1.04), as compared with groups B (1.03 ± 1.41) and C (0.43 ± 1.09; Fig 6).

A paired sample test showed a significant difference between the RTV only in group A (P = .000). No significant difference was found in group B (P = .101) or group C (P = .330; Table 3).

One-way ANOVA demonstrated significant differences in RTD among all the groups (P = .001). A Tukey post hoc test for multiple comparisons demonstrated that group A was significantly different from groups B (P = .009) and C (P = .001). However, no significant differences were reported between groups B and C (P = .622; Table 4).

DISCUSSION

A sample size consisting of 21 implant assemblies was the minimum number of samples to provide approximately 85% power (SD = 1, effect size = 2).

In this study, the abutment screw stability was investigated and not the prosthetic screws. Therefore, metal superstructures were fabricated to simulate the clinical condition of cement-retained implant prostheses. This approach was utilized to eliminate the need for using prosthetic screws, which had the potential to come loose during the test. The absence of simulated proximal contacts in the model is considered a limitation, and the lateral loading is expected to cause more screw instability than the clinical conditions.

The use of the optimal tightening torque is critical for ensuring the stability of the implant-abutment screw joint.19 The Tonichi torque gauge, which was used for screw tightening and measuring the RTVs, has been used by several authors.28–30 According to the manufacturer’s specifications, the error produced by this type of electronic torque gauge is approximately 2%.

In this study, each abutment screw was subjected to six cycles of tightening and loosening during the experiment. According to Weiss et al, the Straumann system demonstrated an average of 3% torque loss in the first 10 opening-and-closing cycles.30

A positive value of the RTD was found in all of the groups, with the exception of two samples in groups B and C. This outcome was the opposite of that in other studies, which reported negative RTD values. This different outcome may be due to the different implant systems used in each study. Khraisat et al27 used the external-hexagon Brånemark implant system (Nobel Biocare), while Yao et al31 used the 3i implant system (Biomet 3i), with internal hexagonal connections.

In a systematic review performed by Gracis et al, the authors reported that the type of implant connection affects the screw joint stability. Implant systems with external connections demonstrated a higher incidence of abutment screw loosening as compared to implants with internal connections.32 Micromovements of the abutments in the external connection design may be responsible for the instability of the screw joint.33,34

In the present study, the internal conical connection between the abutment and the implant (which is an 8-degree Morse taper) combined with the internal octagon key design (provided in that system) contributed to the vertical positioning and self-locking characteristics.35 Additionally, the mechanical friction grip, with a gap of less than 10 μm, decreases the loosening rates to almost zero and enhances the ability of the system to resist bending forces.36,37

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean difference</th>
<th>Standard error</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A B</td>
<td>2.14</td>
<td>0.64</td>
<td>.009*</td>
</tr>
<tr>
<td>C</td>
<td>2.74</td>
<td>0.64</td>
<td>.001*</td>
</tr>
<tr>
<td>B A</td>
<td>−2.14</td>
<td>0.64</td>
<td>.009*</td>
</tr>
<tr>
<td>C</td>
<td>0.60</td>
<td>0.64</td>
<td>.622</td>
</tr>
<tr>
<td>C A</td>
<td>−2.74</td>
<td>0.64</td>
<td>.001*</td>
</tr>
<tr>
<td>B</td>
<td>−0.60</td>
<td>0.64</td>
<td>.622</td>
</tr>
</tbody>
</table>

*Statistically significant at the .05 level.
The increases in mean RTV after lateral loading were 10%, 3%, and 1% in groups A, B, and C, respectively. This outcome was consistent with results from other studies. Sutter et al and Squier et al found that the loosening torque was 7% and 6% higher than the tightening torque under dynamic loading.\(^{38,39}\) Tsuge and Hagiwara found a 10% increase in torque values.\(^{40}\) In comparison, Scacchi et al reported that the loosening torque was almost the same as the tightening torque, while Norton reported a 10% to 20% torque loss.\(^{37,41}\) These variations could be due to different loading conditions, the number of torque and detorque cycles, or errors in torque measurements related to the accuracy of the torque controller.

The difference between the preloading and postloading RTVs was significant only in group A. This outcome may be due to the positioning of the implants in a straight configuration in relation to the prosthesis. According to Skalak,\(^{42}\) cantilever forces and the geometric location of the implant alter the force distribution pattern.

In the present study, there was no statistically significant difference between groups B and C. These results were comparable to the results reported by Yao et al, who found that the direction of the twisting moment applied to centrally positioned implants (in relation to the prosthesis) had no significant effect on joint stability. Their finding was attributed to the anti-twisting mechanism of the internal-hexagon connection present in the Biomet 3i implant system.\(^{31}\)

The null hypothesis was rejected because there were significant differences between group A and the other groups. However, the results showed an increase in the RTD in all groups. Groups B and C demonstrated lower values as compared with group A, which may be explained by the compromised position of the implants in an off-axis relationship to the superstructures. Because of the off-axis implant position, groups B and C were subjected to a greater magnitude of bending and twisting moments as compared with group A. In group A, the estimated twisting moment was equivalent to 320 Nmm (32 Ncm), which is the force (80 N) multiplied by the distance between the loading point and the center of the implant (4 mm).\(^{43}\) In groups B and C, where the loading point was 6 mm from the center of the implants, the generated twisting moment was 480 Nmm (80 N \( \times \) 6 mm), which was greater than that calculated for group A. Moreover, the cantilever design of the prosthesis increased the magnitude of the bending moments on the implants. Jivraj and Chee reported that placement of the restoration too far from the adjacent tooth contributed to the development of unfavorable contours and cantilever forces on the implant.\(^{14}\) In cases of full-arch implant-supported fixed prostheses with distal cantilevers, a dramatic increase in the bending moment will be transferred to the distal implant when force is applied to the cantilever.\(^{44}\) Similarly, the cantilever forces in groups B and C altered the mode of implant loading and increased the bending moment, which affected the stability of the abutment screw. According to Khraisat et al, bending may increase the fatigue of the screw and may result in screw loosening in the external-hexagon implant systems.\(^{27}\) In another study, Bakaeen et al evaluated the in vitro effects of placement of two types of crowns: those containing narrow (8.4 mm) and wide (9.8 mm) buccolingual widths on wide-diameter Nobel Biocare implants (5 mm). The results demonstrated that the reduction of RTVs after simulated function was significant in crowns with wide occlusal tables.\(^{24}\) In the present study, the RTVs of groups B and C, which resembled a wider occlusal table, were also reduced compared with group A. These results were similar to the results of Bakaeen et al.\(^{24}\) However, the mean RTV recorded in groups B and C was greater than 32 Ncm. It seems that the Straumann implant system demonstrated a high resistance to bending and twisting moments. These results are similar to the results of Norton, who found that implant systems with a conical joint design, such as Straumann and Astra, had high resistance to bending moments (which exceeded the levels expected in clinical situations).\(^{45}\) According to a hypothetical model by Weinberg, 1 mm of horizontal implant offset results in an average of 15% increase in moment production.\(^{46}\) In the present study, the effect on the RTV was minimal and could be considered clinically insignificant in the Straumann implant system.

Based on the results of the present study, the internal-octagon implant design may be considered an alternative option in cases where off-axis implant placement is unavoidable. This option may reduce the risk of abutment screw loosening in single implant-supported prostheses in the studied implant system.

**CONCLUSIONS**

After accounting for the limitations of the study, the following conclusions can be drawn.

Placement of implants in an off-axis position relative to the prosthetic crown resulted in a significantly lower RTV as compared with a straight implant configuration. However, the reduction in newton centimeters in the studied implant system is small and is considered to be clinically insignificant.

There was no significant difference found in RTV between clockwise and counterclockwise twisting moments.

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