Capacity to Maintain Placement Torque at Removal, Single Load-to-Failure, and Stress Concentration of Straight and Angled Abutments

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Because the main complication of implant-supported prostheses is torque loosening and/or fixation screw fracture, the goal of this study was to evaluate the torque before and after fatigue (screw placement and removal, respectively), single load-to-failure (compression test), and stress concentration of straight and angled abutments. Eighty implants were included in polyurethane cylinders. Half of the implants received straight abutments (group S, n = 40) and the other half received angled abutments (group A, n = 40). The abutments for cemented prostheses were installed with a torque of 20 Ncm. Eighty titanium structures were machined and cemented on the abutments with zinc-phosphate cement. After storage for 24 hours, half of the specimens had their torque loosening evaluated and were then immediately submitted to a compressive test in a universal testing machine (1 mm/minute, 1,000 kgf), while the other half were subjected to cyclic fatigue (200 N at 2 Hz for 2 × 10⁶ cycles at 37°C) as an aging protocol (n = 20 from each group). The aged samples then had their torque loosening measured and were also submitted to the compression test. Representative samples were evaluated by scanning electron microscopy. Two bidimensional models similar to the in vitro specimens were created and analyzed using the finite element method to evaluate the stress concentration. Data from the in vitro tests were submitted to two-way analysis of variance and Tukey test, both with significance at P = .5. The results show that angled abutments are less capable of maintaining the installation torque and are less resistant during the single load-to-failure test. The von Mises stress concentration was higher for group A in the cervical region. The straight abutments have better prognosis than angled abutments and less susceptibility to mechanical failures. Int J Periodontics Restorative Dent 2019;39:213–218. doi: 10.11607/prd.3998

Despite the proven success of implant-supported prostheses, this treatment may be impaired due to biologic or mechanical causes. The main biomechanical complication of this treatment is torque loosening and/or fixation screw fracture.¹ The load applied in the screw is called torque and can be manually applied via a torque meter. The use of calibrated devices is related to good treatment performance.² When the screw is tightened, a suitable amount of load is required for a stable joint. Thus, failures related to this factor can occur due to both insufficient load, in which the driving forces promote screw fatigue and torque loosening, as well as due to excessive torque, where there will be a failure resulting from screw thread deformation.³

When torque is applied during screw placement, a compressive residual force is generated between the components, called preload. This load is responsible for maintaining a stable union.⁴ Thus, it is correct to state that the success of the screw-retained connection is directly related to the screw condition and preload maintenance.⁵ It is in the dentist’s interest to know controllable factors to avoid prosthetic screw-loosening problems. As the implant installation is not always performed in an ideal way, it is necessary to use abutments for...
angulation correction. When using this type of prosthetic component, the prosthesis/implant system is more susceptible to increased concentrations of stress. However, there are no reports on the effect of torque loosening after fatigue.

In addition to the screw torque-loosening, screw fracture is also reported as a possible failure to be observed in laboratory studies. Thus, the goal of this study was to evaluate the capability of torque to remain the same at screw placement and removal, the single load-to-failure with and without mechanical aging, and the stress concentration between straight and angled abutments for Morse-taper implants. The null hypothesis was that there would be no differences in the torque and mean values of load-to-failure before and after fatigue, or stress concentration between straight and angled abutments.

Materials and Methods

Sample Preparation

Eighty Morse-taper implants (Implacil De Bortoli, Materiais Odontológicos) with 3.75-mm diameter × 10-mm height were used. The implants were embedded with 3 mm of exposed threads at the center of polyurethane cylinders (15-mm height × 10-mm diameter), following ISO 14801. The samples were randomly divided into two groups according to the conical abutments (3.5 × 4.0 mm) for unitary cemented prosthesis. Half of the specimens (n = 40) received a straight abutment (group S), and the other half (n = 40) received a 15-degree angled abutment (group A).

The abutments were tightened to the dental implant with 30 Ncm (initial torque) using a digital torque gauge (TQ 680, Instrutherm Measurement Instruments). Screw-removal torque was measured 5 minutes later (removal torque) with the same digital torque gauge.

Titanium frameworks were fabricated using the computer-aided design/computer-assisted manufacturing (CAD/CAM) technique to represent a unitary implant-supported prosthesis according to ISO 14801. With the abutments already installed, the prostheses were cemented with zinc-phosphate cement (SS-White) with a controlled pressure of 750 g and stored for 24 hours.

Compression Test

After complete cement polymerization, half of the specimens from each group (n = 20 for both groups S and A) were immediately submitted to the compression test. For that, the samples were inserted in a stainless-steel base angled 30 degrees from the ground, following ISO 14801 (Fig 1). The compression load was applied to each implant/abutment assembly by a unidirectional vertical platform and loaded with a rate of 0.5 mm/minute until failure, defined as a fracture of the implant body or the implant-abutment interface. The maximum load to failure (in Newtons) was recorded.

Aging

The other half of each group were aged to evaluate the influence of mechanical cycling on the load-to-failure values and to compare the results with data from the non-aged group. For the fatigue aging, each specimen was positioned on a metal base at 30 degrees to receive a load of 200 N at a frequency of 2 Hz for 2 × 10⁶ cycles, with load-free as the minimum load condition.

Torque Evaluation

All specimens had their torque measured before the compression test. The removal torque loss for the abutments was calculated based on the formula: Preload efficiency (%) = (removal torque/tightening torque) × 100.

Strain Measurement

To perform correct modeling for the computational simulation, one non-aged sample from each group (S and A) was embedded in acrylic resin and cut longitudinally into two parts with a low-speed diamond saw with water-cooling (Isomet 1000, Buehler). Each part was examined and photographed by stereomicroscopy (Stereo Discovery V20, ZEISS) under x7.5 magnification (Fig 2). The photographs were used to model the bi-dimensional geometric models. The samples were modeled using computer-aided software (Rhino version 5.0 SR8, McNeel). Next, a cemented prosthesis was modeled...
as the in vitro method. Each planar geometry was imported to analysis software (ANSYS 17.2, ANSYS) in STEP format and tetrahedral elements formed mesh after the mesh convergence test. The material properties were assigned to each solid component and considered as isotropic and homogeneous. Young’s modulus of titanium (110 GPa) and polyurethane (3.6 GPa) with the same Poisson’s ratio (0.3) was calculated to perform a static mechanical analysis. The friction coefficient (μ) was set as 0.3 between all the titanium–titanium interfaces and 0.65 for the resin-implant interface. An application of an oblique load (30 degrees, 200 N) was defined on the external surface of the prosthesis. The restriction was set on the polyurethane at the Z-axis, allowing lateral deformation. Results were obtained using von Mises stress criteria for metallic solids.

Statistical Analysis

Compression test and torque evaluation results were submitted to a general linear model for two-way ANOVA repeated measures analysis. The factors were defined as “abutment type” (straight or angled) and “aging” (with or without). Tukey test was used to evaluate the comparisons between groups. \( P \leq .5 \) was considered significant for all tests.

Results

Regarding fatigue cycling, straight abutments presented a significantly higher capacity for torque to remain the same at screw loosening than
angled abutments (Table 1) and significantly higher strength under compressive load (Table 2). Mechanical cycling significantly decreased the removal torque’s ability to maintain its values at screw placement and decreased the compressive strength for both abutments. A significant difference in biomechanical behavior was noticed between the groups, with the angled abutment presenting higher von Mises stress concentration in the cervical area (Fig 3). The stress peak values did not exceed 110 MPa.

**Table 1** Mean Values and Standard Deviations (SD) of Torque Loosening

<table>
<thead>
<tr>
<th>Abutment configuration</th>
<th>Fatigue cycling</th>
<th>Mean (%)</th>
<th>SD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angled</td>
<td>Without</td>
<td>72.9</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>With</td>
<td>63.7</td>
<td>14.4</td>
</tr>
<tr>
<td>Straight</td>
<td>Without</td>
<td>83.5</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>With</td>
<td>85.7</td>
<td>19.1</td>
</tr>
</tbody>
</table>

Different superscript capital letters represent statistical difference (Tukey test).

**Table 2** Mean Values and Standard Deviations (SD) of Compressive Test Results

<table>
<thead>
<tr>
<th>Abutment configuration</th>
<th>Fatigue cycling</th>
<th>Mean (N)</th>
<th>SD (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angled</td>
<td>Without</td>
<td>293.51</td>
<td>88.61</td>
</tr>
<tr>
<td></td>
<td>With</td>
<td>245.50</td>
<td>78.30</td>
</tr>
<tr>
<td>Straight</td>
<td>Without</td>
<td>409.91</td>
<td>28.42</td>
</tr>
<tr>
<td></td>
<td>With</td>
<td>355.63</td>
<td>27.80</td>
</tr>
</tbody>
</table>

Different superscript capital letters represent statistical difference (Tukey test).

**Discussion**

The goal of this study was to evaluate the torque loosening, maximum fracture load under compression, and stress concentration of straight and angled abutments for Morse-taper implants. A difference was observed between the abutments for the evaluated factors, thus rejecting the null hypotheses.

Screw joint failure is a significant problem and may be related to preload loss of compressive residual force. Studying the torque and tightening force exerted on a screw is important, as preload of the screw joint is responsible for maintaining a stable bond between the components, and loosening of the prosthetic parts is reported as a main factor in failure of implant-supported prostheses.

The studied groups herein presented significant differences after mechanical cycling. Several studies report that early screw failure is uncomfortable for the patient and is a
main reason for additional implant-prosthesis maintenance. The factors reported in the literature that enable dental surgeons to avoid early preload loss are the choice of an adequate prosthetic connection and a suitable restorative material, a sufficient number of installed implants, and the use of prosthetic screws with wear-resistant metal alloys. Despite this, abutments for angulation correction are widely used and their removal torques have not been evaluated for the ability to maintain placement torque compared to straight abutments.

In the present study, compared to straight abutments, the angled abutments or those for angulation correction are less effective in maintaining preload during mechanical fatigue during $2 \times 10^6$ cycles. Thus, these abutments are more susceptible to the clinical failures that are reported with screw problems and may require further maintenance by the dental surgeon. This data may explain why there is a higher percentage of angled-abutment screw failures compared to straight abutments.

The maximum fracture load of the components showed that angled abutments are also more susceptible to fracture because they have lower mechanical resistance to compression than straight abutments. Despite this, both abutments were affected by mechanical fatigue and showed a significant decrease in their fracture load. It is reported that increased angulation of zirconia abutments make them more susceptible to fracture. Thus, the angled titanium abutments herein were less resistant than straight abutments, thus corroborating studies demonstrating early fractures in angled abutments.

Both strength and screw torque seem to be directly related to the stress generated in the prosthesis/implant system by occlusal forces during axial loading. Thus, a computational calculation was made based on the bi-dimensional geometry of a specimen following the in vitro test parameters. Although the bi-dimensional analysis does not show as much information as a three-dimensional analysis and has a limited interpretation of maximum stress (colorimetric maps express red fringes generated in the cervical region of the implant), it can be performed to verify the maximum stress with a gain in processing time. Thus, the results demonstrate that the von Mises stress map is more aggressive in the angled abutment group, with fringes representing larger scattered magnitudes and larger areas. With the same applied force, a higher stress concentration is generated only by altering the prosthetic component, thus suggesting a greater probability of mechanical problems. These results justify the findings of the laboratory test and are in agreement with the literature, since previous studies have defined angled abutments as prone to more stress than straight abutments.

Conclusions

Despite these study limitations, it can be concluded that the use of angled abutments for Morse-taper implants makes the rehabilitation more susceptible to abutment screw loosening, less resistant to compressive load, and receptive to greater stress concentration than straight abutments.

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References


