Loosening torque of abutment screws is a frequent prosthetic complication in implant dentistry,\textsuperscript{1,2} especially for external hexagon connections\textsuperscript{3–5}; the dental implant literature reports a higher incidence of complications related to this implant connection.\textsuperscript{6} New solutions need to be developed for cases in which implants that were placed years ago are now presenting prosthetic complications.\textsuperscript{7}

Some authors have stated that the abutment screw design interferes with its application as a union agent.\textsuperscript{8–11} A conical head screw design for a single-tooth abutment (Fig 1) was developed to preserve the initial applied torque.\textsuperscript{12} Abutment screws create a friction mechanism between the head of the screw and the inner surface of the abutment; it was hypothesized that the conical head screw shape increases the contact area, increasing friction and resistance to micromovements during loading.\textsuperscript{12} In the present situation, the design of the conical head screw

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**Purpose:** New solutions need to be developed for cases in which implants that were placed years ago are now presenting prosthetic complications. A conical head screw design for a single-tooth abutment was developed to preserve the initial applied torque. The aim of this study was to assess the preload maintenance of different screw design sets (a conical head screw set and a flat head screw set) for single-tooth abutments in external hexagon implants, verifying whether reverse torque changes after mechanical loading at different crown/implant ratios and to understand if the use of the tested conical head screw set design can help clinicians solve loosening torque. **Materials and Methods:** Forty external hexagonal implants, 40 single-tooth abutments, 20 conical head screws, and 20 flat head screws were split into four groups with different crown/implant ratios (crown/implant ratio > 1 or crown/implant ratio < 1). The abutments were attached to the implants by applying a torque of 35 Ncm; the specimens were mechanically loaded for 1 million cycles, and the loosening torque was checked and recorded with a digital torque wrench. The Kruskal-Wallis test ($P = .05$) and Wilcoxon test were performed to assess the results. **Results:** In all groups, at least one specimen kept 100% of the initial applied torque before mechanical loading ($t_0$). After mechanical loading ($t_1$), all specimens presented torque reduction. The Kruskal-Wallis test was performed, and the flat head screw $t_0$ group presented lower torque maintenance and a significant difference ($P < .05$) compared with the initial applied torque and with the conical head screw $t_0$ group. The conical head screw $t_0$ group presented a higher torque maintenance and no significant difference ($P > .05$) compared with the initial applied torque. For the flat head screw, the crown/implant ratio affected the torque maintenance. For the conical head screw, the crown/implant ratio did not affect the torque maintenance ($P > .05$). **Conclusion:** The conical head screw set presented a higher maintenance of applied preload than the flat head screw set. As far as reverse torque is concerned, the crown/implant ratio affects the torque maintenance only in association with a flat head screw set. The use of the tested conical head screw set can help clinicians solve loosening torque, mainly in a situation with a crown/implant ratio > 1. **Keywords:** dental implantation, dental prosthesis, implant-supported, torque

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matches the conical head against the screw seat. A conical screw against a conical screw seat increases the area of contact and increases the longevity of the screw joint.

When an abutment is jointed to an implant by tightening the abutment screw, there are three contact forces: (1) at the abutment-to-abutment screw interface; (2) at the abutment-to-implant interface; and (3) at the abutment screw thread-to-implant inner threaded bore interface. Preload is the axial force in the neck of the screw, between the first mating thread and the head of the abutment screw. During abutment screw tightening, the applied torque develops a compressive force within the screw stem, generating a clamping force at the interface between the implant and the abutment. Preload is a direct determinant of clamping force.

Another factor that may be associated with prosthetic failures is an increase in the crown/implant ratio. A crown/implant ratio > 1 may have a stress concentration area that is up to three times larger compared with a crown/implant ratio < 1, with higher stress on the abutment screw; depending upon how much greater the differential is between crown/implant ratios, it can be larger than three times.

Currently, tapered implant connection systems have conical head screws for the fixation of single-tooth abutments, whereas external hexagon, internal hexagon, and internal tri-channel implant connections have flat head screws. In this study, the concept of conical head screw was used in external hexagon connections.

The aim of this study was to assess the preload maintenance of different screw design sets (a conical head screw set and a flat head screw set) for single-tooth abutments in external hexagon implants, verifying whether reverse torque changes after mechanical loading at different crown/implant ratios and to understand if the use of the tested conical head screw set design can help clinicians solve loosening torque.

**MATERIALS AND METHODS**

**Material Selection**

Forty external hexagon implants (Dérig) were selected, each with a 10-mm length and 4.1-mm platform diameter. Twenty flat head screws (Fig 2) and 20 conical head screws (Fig 1) (Dérig) were selected. Forty single-tooth abutments (Dérig) were selected (10 abutments with 9.8-mm height, each featuring an internal geometry with an attachment for a flat head screw; 10 abutments with 6.0-mm height, each featuring an internal geometry with an attachment for a conical head screw; and 10 abutments with 6.0-mm height, each featuring an internal geometry with an attachment for a conical head screw). Forty hemispherical loading components were used. The fixation of the hemispherical component increases the coronal section by 3 mm.

Within the limitation of the components and the mechanical loading machine used, the heights between 9.8 mm and 6 mm of the abutments were selected, since these heights are the highest and the lowest possible, respectively.

All components used in this study were experimental and were manufactured exclusively for this use. All components were supplied by the same manufacturer and turned on using the same machines and tools, which ensured that the quality of both screw designs was the same.

**Measuring the Surface Areas of the Screws**

Components were designed and analyzed using the three-dimensional (3D) SolidWorks software (Dassault Systèmes SolidWorks). The digital designs of the screws were created by a mechanical engineer, as most of the designs are in implant dentistry, and loaded into the 3D SolidWorks software, which calculated the surface areas between the screw used in this study and the inner surface of the abutment.

**Division into Groups**

The implants, abutments, and screws were split into four groups:

- **Flat head screw and crown/implant ratio > 1 group:** 10 specimens with crown/implant ratio > 1, each abutment with 9.8-mm height and attached to a flat head screw and hemispherical loading component (Fig 3)
- **Flat head screw and crown/implant ratio < 1 group:** 10 specimens with crown/implant ratio < 1, each abutment with 6.0-mm height and attached to a flat head screw and hemispherical loading component (Fig 4)
Conical head screw and crown/implant ratio > 1 group: 10 specimens with crown/implant ratio > 1, each abutment with 9.8-mm height and attached to a conical head screw and hemispherical loading component (Fig 5).

Conical head screw and crown/implant ratio < 1 group: 10 specimens with crown/implant ratio < 1, each abutment with 6.0-mm height and attached to a conical head screw and hemispherical loading component (Fig 6).

The group sample size was defined based on previous studies that followed the same methods of this research.

Placement of the Specimens
All 40 implants were embedded in acrylic resin (Jet, Clássico) in plastic tubes that were 20 mm in diameter and 31 mm high, such that their central axes had a 30-degree inclination in relation to the loading direction of the testing machine, simulating the cusp inclination of the antagonist tooth on the implant longitudinal axis. The abutments were attached to the implants by applying a torque of 35 Ncm according to the manufacturer’s instructions, and, after 10 minutes, the screw was retightened to 35 Ncm to minimize loosening between the threads, which helped achieve the ideal preload. Loosening torque before mechanical loading (t0) was verified 5 minutes after the initial torque was applied through a digital torque wrench (TQ-680, Instrutherm Measurement Instruments), and the data were recorded. The screw was tightened again to 35 Ncm and retightened to 35 Ncm after 10 minutes. Placement of the specimens followed the recommendations of the Brazilian National Standards Organizations – NBR ISO 14801:2012.

Mechanical Loading
The specimens were placed on the testing machine of the Department of Prosthetics at the School of Dentistry of University of São Paulo for mechanical loading. The mechanical loading operates with a loading rate of 120 cycles/min (2 Hz). Each test group was cycled for 139 hours, totaling $1.0 \times 10^6$ cycles (1 million cycles), which represents 40 months of simulated masticatory function. The implant/abutment specimens were removed from the testing machine, and after mechanical loading (t1), the
loosening torque was verified and recorded with a digital torque wrench.

The percentage (%) of torque maintained before \( (t_0) \) and after \( (t_1) \) mechanical loading was calculated by the following formula:

\[
\text{Preload loss (％)} = \frac{(\text{Initial removal torque} - \text{postload removal torque})}{\text{Initial removal torque}} \times 100
\]

**Statistical Analysis**

The Kruskal-Wallis test \((P = .05)\) and Wilcoxon test were performed to assess the results.

**RESULTS**

Figures 7 and 8 show the surface area of the flat head screw and conical head screw, respectively, using the 3D SolidWorks Software. Data show a different contact area according to the screw head design. The conventional flat head screw design had a contact area of 1.76 mm\(^2\) (Fig 7); the conical head screw had a contact area more than twice as big, of 4.16 mm\(^2\) (Fig 8).

In all groups, at least one specimen kept 100% of the initial applied torque before the mechanical loading \((t_0)\). After mechanical loading \((t_1)\), all specimens presented torque reduction. Table 1 shows the results.

When comparing the isolated effect the head screw design had on the initial applied torque (35 Ncm = 100%) versus torque maintenance before mechanical loading \((t_0)\), once the crown/implant ratio does not affect these variables, the flat head screw and crown/implant ratio > 1 group was associated with the flat head screw and crown/implant ratio < 1 group (flat head screw \(t_0\)) and was compared with the association between the conical head screw and crown/implant ratio > 1 group and conical head screw and crown/implant ratio < 1 group (conical head screw \(t_0\)). The Kruskal-Wallis test was performed, and the flat head screw \(t_0\) group presented lower torque maintenance and a significant difference \((P < .05)\) compared with the initial applied torque.

The intragroup evaluation of the torque maintenance was performed according to mechanical loading \((t_0 - t_1)\). A pairwise comparison (Table 2) showed that the mechanical loading decreased the torque maintenance in all groups (Wilcoxon, \(P < .05\)).

Figure 10 shows a box plot of all groups for both \(t_0\) and \(t_1\). Intergroup evaluation was performed (Kruskal-Wallis, \(P = .05\)) to compare both the crown/implant ratio and screw design after mechanical loading \((t_1)\). For the flat head screw, the crown/implant ratio affected the torque maintenance. The flat head screw and crown/implant ratio >1 group showed the lowest torque value maintenance after mechanical loading,
which differs from all other groups \((P < .05)\). However, when the crown/implant ratio < 1 (flat head screw and crown/implant ratio < 1 group), the results were similar for the conical head screw \((P > .05)\), regardless of the crown/implant ratio (conical head screw and crown/implant ratio > 1 group and conical head screw and crown/implant ratio < 1 group). For the conical head screw, the crown/implant ratio did not affect the torque maintenance \((P > .05)\).

**DISCUSSION**

According to Binon and McHugh, a screw connection could be more resistant to screw loosening through the elimination of misfits between the abutment and implant. This study shows that the conical head screw has a contact area more than twice as big as that of the flat head screw, which improves the use of the conical head screw, as stress is dissipated over a bigger area, providing the assembly with more stable mechanical bonding.

Different screw designs have been utilized throughout the years. The present study shows results related to a specific screw design with an angle of 25 degrees.

Previous studies have evaluated the interference of the screw design in preload; however, no previous study has related this factor and crown/implant ratio. The present study considered the conical head screw as a possibility to understand prosthetic failures in external hexagon implants, such as loosening torque. This type of failure is frequent, as 11.7% with an average of 3.2 years elapsed from prosthesis insertion to screw loosening; therefore, this study can help clinicians make decisions.

When the performance of the screw was evaluated, before mechanical loading, a statistical difference was not found between the initial applied torque and the removal torque for the conical head screw. In turn, the flat head screw removal torque was different from the initial applied torque. Therefore, the results showed that the conical head screw has better maintenance of initial applied torque than the flat head screw, regardless of the moment,

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Flat head screw</th>
<th>Conical head screw</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Crown/implant ratio &gt; 1</td>
<td>Crown/implant ratio &lt; 1</td>
</tr>
<tr>
<td>t0</td>
<td>t1</td>
<td>t0</td>
</tr>
<tr>
<td>1</td>
<td>91.43</td>
<td>74.29</td>
</tr>
<tr>
<td>2</td>
<td>85.71</td>
<td>82.86</td>
</tr>
<tr>
<td>3</td>
<td>91.43</td>
<td>65.71</td>
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<td>71.43</td>
</tr>
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<tr>
<td>6</td>
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<td>65.71</td>
</tr>
<tr>
<td>Mean</td>
<td>90.57</td>
<td>68.57</td>
</tr>
<tr>
<td>SD</td>
<td>8.73</td>
<td>6.46</td>
</tr>
</tbody>
</table>

**Table 2 Mean and SD of Initially Applied Torque and \(P\) Value of Wilcoxon Test**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Categories</th>
<th>Maintenance of initially applied torque (%)</th>
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<tr>
<td></td>
<td></td>
<td>t0</td>
</tr>
<tr>
<td>Crown/implant ratio &gt; 1</td>
<td>Flat head screw</td>
<td>90.6</td>
</tr>
<tr>
<td>Crown/implant ratio &lt; 1</td>
<td>Flat head screw</td>
<td>84.9</td>
</tr>
<tr>
<td>Crown/implant ratio &gt; 1</td>
<td>Conical head screw</td>
<td>96.6</td>
</tr>
<tr>
<td>Crown/implant ratio &lt; 1</td>
<td>Conical head screw</td>
<td>98</td>
</tr>
</tbody>
</table>

*Significant difference \((P < .05)\).
which is a clinical benefit, related to the specific design tested.

The fact that the abutment screw design influences the removal torque is well-known, but the results are divided. Two studies showed that the conical head screw increases removal torque, and two other studies showed that the conical head screw decreases removal torque.

To analyze the results that diverged from this study by comparing the results of Jörnéus et al and the present study is not an easy task, as the latter used only titanium screws (Ti-6Al-4V alloy), while the former compared grade I commercially pure titanium, grade III commercially pure titanium, and gold alloy. The elasticity of the material used in screw manufacture is important to preload. When titanium screws (Ti-6Al-4V alloy) are compared with gold screws after simulated mechanical loading, the raw material used in their manufacture plays a role in loosening, but titanium screws are less prone to it.

The present study observed the interference of crown/implant ratio > 1 contributing to screw loosening only when the conical head screw was used, the crown/implant ratio > 1 contributing to screw loosening only when the flat head screw was used. In cases where the conical head screw was used, the crown/implant ratio did not affect the torque maintenance. For these cases (conical head screw use), the present results are in agreement with the results published by Nedir et al and Tawil et al. According to Tawil et al, a higher crown/implant ratio will not represent a major biomechanical risk factor.

Considering the results of this study, in an external hexagon implant crown/implant ratio > 1 clinical situation, a conical head screw must be used, so better maintenance of the initial applied torque will be achieved. The use of the conical head screw improved the external hexagon implant, being advantageous in the clinical setting. In the daily clinic, these results can also be applied considering the demand of short implants and implants that presented bone loss, increasing the crown/implant ratio.

In this study, all screws were tightened to 35 Ncm, considering the importance of locking for the stability of the implant/abutment assembly, and following the manufacturer’s instructions. The standard reached during the placement of the specimens helped ensure that the screw design and crown/implant ratio were the only variables in this study. A digital torque wrench was used, and despite the effort to keep it centralized, any slack could produce an inclination toward the axis of the implant, which could interfere with the torque measurement. If such an inclination did occur, it was negligible and distributed equally into all samples. The fact that any misfit could interfere with the torque measurement was a limitation. Another limitation was “in vitro” study, with handle variables, unlike a clinical situation. Further studies are highly recommended to test the different abutment screw designs in clinical situations.

The conical head screw to external hexagon implants tested in this research is not available from the market, but it could be a product offered by companies to reverse loosening clinical problems.

CONCLUSIONS

The conical head screw set presented higher maintenance of applied preload than the flat head screw set. As far as reverse torque is concerned, the crown/implant ratio affects the torque maintenance only in association with a flat head screw set. The use of the tested conical head screw set can help clinicians solve loosening torque, mainly in a crown/implant ratio > 1 situation.

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