Purpose: To evaluate the implant-abutment interface area and the abutment screw loosening value when diamondlike carbon (DLC)-coated or titanium screws were used before and after cyclic loading. Materials and Methods: Thirty-six implants were divided into four groups according to the type of connection (external hexagon [EH] or internal hexagon [IH]) and the type of abutment screw (with [EHD/IHD] or without [EHT/IHT] DLC coating). The implants were placed in epoxy resin–glass fiber composite, and crowns cast in a metal alloy were screwed to the implants. The implant-abutment interface was measured before (VG1) and after (VG2) cyclic loading. The removal torque values were recorded. Results: In groups with titanium screws, there was an increase in the implant-abutment interface area from VG1 to VG2, whereas in groups with DLC-coated screws, the interface area was reduced (EHT = 4.49%, IHT = 24.32%, EHD = –1.05%, IHD = –9.95%). In the IHT group only, the implant-abutment interface area showed a statistically significant difference between VG1 and VG2. The Pearson correlation indicated no significant differences among the studied factors, where R = –0.11 for EHT, 0.14 for EHD, 0.07 for IHT, and 0.43 for IHD. Conclusions: The implant-abutment interface areas in groups with an EH connection were larger than those in groups with an IH connection, regardless of the type of screws used. The screw loosening values decreased in all groups after cyclic loading. No correlation between the implant-abutment interface area and the screw loosening value was seen. Int J Oral Maxillofac Implants 2012;27:xxx–xxx.

Key words: dental implants, implant screw, marginal adaptation
cellent wear resistance make DLC a superior material for use as a protectant and lubricant.\textsuperscript{14} DLC films with various atomic bond structures and compositions are being used in orthopedic, cardiovascular, and dental applications.\textsuperscript{17}

Additionally, with implants expected to serve for decades, fatigue failure may continue to be an issue.\textsuperscript{18} Over 10 years, the reported success rate for implant-supported single crowns is 89.4%, and the most common failures are fracture of the veneering material and loosening of the abutment screw.\textsuperscript{19} Moreover, dynamic loading forces during physiologic activities that do not exceed the maximum resistance of an implant/abutment connection, or even those that are far below this threshold, might gradually loosen the implant-abutment connection or cause a sudden failure of this connection as a result of fatigue.\textsuperscript{18}

The purpose of this study was to evaluate the implant-abutment interface area and screw loosening values when DLC-coated screws or conventional titanium screws were used before and after cyclic loading. The hypothesis was that DLC coating could decrease abutment screw loosening and, consequently, lead to a smaller interface and smaller differences between initial and final torque values.

**MATERIALS AND METHODS**

**Manufacturing of Samples**

In all, 36 implants, 36 UCLA-type abutments, 18 conventional titanium screws, and 18 DLC-coated screws (Neodent) were used in this study. The samples were divided into four groups of nine specimens each according to the type of implant connection and screw used: EHT = external hexagon and conventional titanium screw, EHD = external hexagon and DLC-coated screw, IHT = internal hexagon and conventional titanium screw, and IHD = internal hexagon and DLC-coated screw. Table 1 provides additional information about the materials used in this study.

The dental implants were fixed with the vertical rod of a cast surveyor (Bioart) in an epoxy resin-glass fiber composite (NEMA grade G-10 rod, Piedmont Plastics). This embedment material has an appropriate elastic modulus for a bone analog material (about 20 GPa) that is easily machined and sufficiently tough for cyclic testing.\textsuperscript{20}

The abutment wax-up was performed on the abutments with a standardized height of 8.0 mm without cusps\textsuperscript{21} (Fig 1) and was then duplicated in a polyvinyl siloxane matrix. A nickel-chromium-titanium alloy (Tallium) was used to fabricate the crowns. Before the torque procedure, the crowns were marked at four sites using a carbide bur in a high-speed handpiece to identify the areas that would be used for measurement.

**Testing and Imaging Protocols**

The screws were tightened initially by hand and then with an analog torque meter (Tohnichi BTG60CN), according to the manufacturer’s specifications: 32 Ncm was used for the EH groups and 20 Ncm was used for the IH groups. In vitro studies have demonstrated that internal connections are more stable mechanically than external flat connections\textsuperscript{22,23}; this explains the differences in recommended tightening torques recommended by the manufacturer. After 10 minutes, the screws were re-tightened to compensate for the initial loss of preload.\textsuperscript{24}

The interfaces were analyzed using a stereoscope (Aus Jena, Carl Zeiss) with 100× magnification and were captured by a digital camera (Nikon D70) at the previously defined four sites. The vertical gaps (VGs) were measured three times (Image J Software, National Institutes of Health), and the means were calculated (VG1) (Fig 2).

Next, the samples were mounted in a universal testing machine (Instron 8800) and subjected to a load of 400 N at a frequency of 8 Hz for 1 million cycles. This was done to simulate 1 year of function.\textsuperscript{20,25,26}

After mechanical cycling, the abutment-implant VGs were measured again (VG2) and means were calculated. The crowns were unscrewed, and the removal torque values were measured (RT).

<table>
<thead>
<tr>
<th>Group</th>
<th>Connection</th>
<th>Screw type</th>
<th>Torque</th>
<th>Abutment screw diameter</th>
<th>Diameter of screw hole</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHT</td>
<td>External hex</td>
<td>Titanium</td>
<td>32 Ncm</td>
<td>1.75 mm</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>EHD</td>
<td>External hex</td>
<td>DLC-coated</td>
<td>32 Ncm</td>
<td>1.75 mm</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>IHT</td>
<td>Internal hex</td>
<td>Titanium</td>
<td>20 Ncm</td>
<td>1.65 mm</td>
<td>1.6 mm</td>
</tr>
<tr>
<td>IHD</td>
<td>Internal hex</td>
<td>DLC-coated</td>
<td>20 Ncm</td>
<td>1.65 mm</td>
<td>1.6 mm</td>
</tr>
</tbody>
</table>
Statistical Analysis
The values of VG1, VG2, and RT were statistically analyzed by two-way analysis of variance and t test with \( P \leq 0.05 \) as the level of significance. A possible correlation was determined with \( r \leq 0.8 \) for the Pearson correlation coefficient and \( P \leq 0.05 \).

RESULTS
Table 2 shows the VG values in each group before and after mechanical cycling (VG1 and VG2), as well as comparisons within and between groups. The groups with DLC-coated screws (EHT and IHT) showed increased VG2 values, whereas the groups of titanium screws (EHD and IHD) showed decreased VG2 values.

Table 3 shows values for torque, RT, and the differences between them. The initial torque decreased in all groups versus the baseline values (Table 3), indicating that, initially, the preload was equally compensated among all groups (torque values). With respect to RT values, statistically significant differences were observed between all groups except for the IHT group.
With respect to the differences in the mean values of the implant-abutment interface area (VG1 and VG2) and the differences between torque and RT, no correlations were seen for any comparison (Pearson correlation coefficient, \( r \geq 0.8; P \leq .05 \)) (Table 4).

### DISCUSSION

The implant-abutment interface has been reported as a primary factor in stress distribution and in adverse biologic responses and other prosthetic complications.\(^6,7,11,13\) A correct fit between an implant and its abutment is directly related to the precision of manufacturing procedures and the torque applied to the abutment screws.\(^10\) It can be evaluated by the gap depth, vertical and horizontal misfit, and rotational freedom.\(^27–30\) This study used the vertical gap because it is the ideal parameter for evaluating cyclic loading, whereas evaluation of the horizontal gap is normally used to determine the precision of casting procedures.\(^27\)

Several studies have reported different values for the implant-abutment interface area. It is agreed, however, that cast abutments generate the largest gaps, followed by cast-on abutments and machined abutments.\(^11,13\) There is no perfect fit between implant and abutment\(^6,31\); however, the smaller gap is, the better the fit is. Marginal misfit between 30 and 200 \(\mu m\) is considered clinically acceptable.\(^32\) Machinable abutments generate gaps around 10 \(\mu m\); gaps of 36 to 86 \(\mu m\) are typical for cast-on abutments and 118.8 \(\mu m\) for cast abutments.\(^27\) It is known that gaps can cause problems because they allow bacterial growth and, consequently, peri-implant soft tissue damage.\(^11–13\) In this study, vertical misfit values were between 59.81 and 73.73 \(\mu m\) for EH assemblies and between 14.47 and 22.54 \(\mu m\) for IH assemblies. The EH groups showed higher values before and after cyclic loading, in agreement with previous studies that evaluated cast-on abutments.\(^27,29,34\)

Another important factor affecting the passivity of the system is the screw itself. When the screw is first tightened, the contact area between the screw and the implant thread generates a compression force—the preload—which is responsible for keeping the implant and the abutment united.\(^5,9,10,25,35\)

To minimize screw loosening, previous studies have proposed new techniques and products.\(^9,14,16,21,36,37\) The DLC-coated screw film possesses properties similar to those of real diamonds, including hardness, wear resistance, and chemical stability. Moreover, low friction resistance and excellent wear resistance make DLC one of the best materials for a protectant and lubricant.\(^14,16\)

Some studies have shown that the stability of the connection and RT may be influenced by the initial torque,\(^5,35,38\) the screw material,\(^12,37\) masticatory strength,\(^25,26,39\) and relaxation of the fit. When initial torque is applied, leveling and accommodation between the screw thread and the implant occur, resulting in a reduction of preload.\(^5\) However, according to Dixon et al.,\(^12\) a reduction in the RT value, in relation to the initial torque applied, is not necessarily harmful if it is not progressive and if the remaining torque is sufficient to prevent failure of the connection.

In this study, higher values for torque loss were observed in the EHD (42.96%) and IHT (43.75%) groups. The least amount of torque loss was observed in the EHT group (33.59%) and the IHD group (31.9%). Most in vitro studies have demonstrated that internal connections are more stable mechanically than external connections.\(^22,23\) The general focus is clearly on deep internal connections, in which the screw takes little or no load and provides intimate contact with the implant walls to resist micromovement.\(^22,23\) Thus, we can assume that the higher RT values seen in the EHD group are a result of the fact that a longer screw was required than for the IHD group. [AU: Have I edited the previous sentence correctly? The original wording was unclear to me.]

### Table 4  Comparisons of Mean Differences Between VG1 and VG2 and Torque (T) and RT Values

<table>
<thead>
<tr>
<th>Groups</th>
<th>VG2 – VG1</th>
<th>RT – T</th>
<th>Pearson ( r )</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHT</td>
<td>2.70</td>
<td>–10.75</td>
<td>–0.11</td>
<td>.76</td>
</tr>
<tr>
<td>EHD</td>
<td>–0.77</td>
<td>–13.75</td>
<td>0.14</td>
<td>.70</td>
</tr>
<tr>
<td>IHT</td>
<td>4.20</td>
<td>–8.75</td>
<td>0.07</td>
<td>.85</td>
</tr>
<tr>
<td>IHD</td>
<td>–1.60</td>
<td>–6.37</td>
<td>0.43</td>
<td>.24</td>
</tr>
</tbody>
</table>

*Statistically significant \( P \leq .05 \).
In this study, all groups showed a loss of torque after mechanical cycling, and screw loosening occurred regardless of the type of connection and screw used. With respect to the RT values of the EHT and EHD groups, both of which featured an EH connection, the EHD group, in which DLC-coated screws were used, lost more torque after mechanical testing. Because DLC coating, an engineering process, reduces the coefficient of friction, therefore making the surface smoother, this effect may account for the observed significant decrease in RT in the EHD group. In contrast, with respect to the RT seen in the IH groups, the greater loss of torque was seen in the IHT group, but the difference versus the IHD group was not statistically significant. According to similar studies in the literature, the number of samples is satisfactory; thus, the absence of statistical difference may only be considered a finding.

The present results indicated no positive correlation between the RT and the mean implant-abutment interface area (Pearson coefficient, \( r \geq 0.8 \)). This lack of a positive correlation between the interface area and the screw loosening value suggests that the higher RT values observed may be merely a coincidence.

This investigation did not address whether bacteria would penetrate the implant-abutment interface of the systems used in this study and lead to colonization. However, the tightening of abutment screws at the torque recommended by the manufacturers could help to minimize microgaps and the potentially adverse effects of microleakage.

In this study, DLC coating did not reduce the RT value and, consequently, did not reduce the implant-abutment interface area and RT. Therefore, other variables should be explored to improve the understanding and potential role of DLC-coated screws in the field of implant dentistry.

**CONCLUSION**

Given the conditions and limitations of this study, the following conclusions can be drawn:

1. The implant-abutment interface areas in assemblies with external-hexagon implants were larger than those of internal-hexagon assemblies, both before and after cyclic loading.
2. The implant-abutment interface in the internal-hexagon group with titanium screws was enlarged after cyclic loading.
3. There was a loss of torque after cyclic loading in all groups.
4. No correlations were observed between the implant-abutment interface area and the removal torque or screw loosening value.
5. Application of a diamondlike carbon coating to abutment screws did not result in a statistically significant decrease in the implant-abutment interface area.

**ACKNOWLEDGMENTS**

The authors gratefully acknowledge the donation of material by Neodent, which allowed this research.

**REFERENCES**


