Performance of different abutment/implant joints as a result of a sealing agent

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Abstract

Purpose: This in vitro study aimed to evaluate the effectiveness of a sealing agent in sealing the abutment/implant interface and the preload maintenance of retaining screws after mechanical cycling.

Methods: Six groups (n = 12) were evaluated according to the abutment/implant system (external-hexagon implant and UCLA abutments, EHU; Morse taper implant and UCLA abutments, MTU; and Morse taper implant and flexcone abutments, MTF) and the presence of an anaerobic gel sealing agent (control group, no sealing agent; experimental group, sealing agent). Toluidine blue (0.7 μL) was inserted into each implant and the abutments were attached to the implants using a digital torque wrench to evaluate the sealing of the abutment/implant interface. The specimens were tested through mechanical cycling (1 × 10⁶ cycles, 2 Hz, and 130 N). Dye release from the abutment/implant interface was analyzed using a spectrophotometer, and the reverse torque values were obtained using a digital wrench. Reverse torque and dye release data were measured after mechanical cycling and analyzed using ANOVA and Tukey’s test (α = .05).

Results: All experimental groups showed higher reverse torque values than the control groups (P <.05). In general, the MTU and MTF experimental groups, as well as the MTF control group, showed no significant dye release at different periods (P >.05).

Conclusions: The use of a sealing agent improved the preload maintenance of screw-retained implant-supported prostheses. The sealing agent was effective in sealing the Morse taper connection.

Keywords: Abutment, Implant-supported prosthesis, Preload, Screw

1. Introduction

Despite the high success rate of dental implants, oral rehabilitation with implants remain prone to complications, failures, and limitations [1–3], particularly with respect to single prostheses. Implant failures can be classified as esthetic [4], biological [5–7], or mechanical [8–14]. The most frequent biomechanical failure is screw loosening and fracture [10], as torque loss is more frequent among single implant-supported prostheses [12,15–17].

Preload is defined as the internal tension generated in the abutment screw after the application of a recommended torque [18,19]. This feature determines the sealing ability of an abutment/implant system, and its maintenance under the stomatognathic system action is indispensable for the stability of the abutment/implant assembly [19]. The parameter is dependent on the insertion torque, components, screw design, and friction coefficient between the surfaces, particularly with regard to Morse taper connections [20]. If the preload decreases under external forces, the stability of the screw joint can be reduced, promoting screw thread slippage and screw loosening [9,12,21].

Increased material roughness and hardness also contribute to the friction coefficient, which can be promoted by component lubrication, thereby reducing the shearing force [22]. Importantly, sealing agents on the screw joint interface can enhance the preload maintenance of retention screws and decrease microleakage and microorganism incorporation into this area. Some studies in the literature show that the Morse cone type is superior to other connections with respect to susceptibility to microbial infiltration [23–28]. However, Alves de Sousa et al. [29] reported that the Morse cone implant system was more susceptible to Enterococcus faecalis and Candida albicans infiltration than the external-hexagon implant system, which could jeopardize the success of oral rehabilitation with dental implants [29].

One of the reasons for implant failure is the prevalence of peri-implant infections affecting the supporting tissues that surround the implanted area, leading to the loss of the adjacent bone [29]. Some microorganism species, in addition to colonizing the external surface of the implant, can also be found at the interface of the implant and prosthesis connection, specifically in the micro-gap formed between the implant and the prosthetic abutment. This situation can be aggravated by the loosening of the screws contributing to peri-implant inflammation [29].

Seloto et al. [22] evaluated the effectiveness of sealing agents in the preload maintenance of external-hexagon retaining screws to minimize the mechanical limitations of these implant systems [22,30]. The application of sealing agents yielded higher reverse torque values of the external-hexagon retaining screws under static conditions [22]. However, it remains unclear if the effectiveness of the sealing agents could be maintained under mechanical cycling conditions and stored in an aqueous environment, such...
as for other implant and abutment systems.
Hence, the purpose of this in vitro study was to evaluate the effectiveness of a sealing agent in the sealing of the abutment/implant interface and the preload maintenance of retention screws with various connection designs under mechanical cycling. The null hypothesis stated that the application of the sealing agent would not influence the sealing of the abutment/implant interface and the preload maintenance after mechanical cycling.

2. Materials and Methods

2.1. Experimental design
A total of 72 implants were tested in this study, including 24 external-hexagon implants (DSP Biomedical, Campo Largo, PR, Brazil; 4.0 × 10.0 mm) and 48 Morse taper implants (DSP Biomedical, Campo Largo, PR, Brazil; 3.5 × 10.0 mm). Initially, the specimens were divided into three groups (n = 24 each): EHU group, external-hexagon implants attached to anti-rotational UCLA abutments (4.0 × 10.0 mm) and retention screws; MTU group, Morse taper implants attached to anti-rotational UCLA abutments (4.4 × 8.1 mm) and retention screws; and MTF group, Morse taper implants attached to flexcone abutments (3.9 × 3.0 mm), titanium cylinders (4.3 × 10.0 mm), and retention screws (DSP Biomedical, Campo Largo, PR, Brazil) (Fig. 1). The above-mentioned groups were each subdivided into two groups (n = 12 each): EHU, MTU, and MTF control groups with no sealing agent at the abutment/implant interface; and EHU, MTU, and MTF experimental groups with the application of a sealing agent to the abutment/implant interface.

Prior to embedding, all implants and prosthetic components were cleaned with deionized water in an ultrasonic bath (Cristofoli, Campo Mourao, PR, Brazil) for 5 min and air dried. All implants were embedded into polyurethane resin (Max Rubber Ind, Diadema, SP, Brazil) at 30° of inclination in relation to their long axis using a two-piece metallic matrix to simulate an oblique loading (Fig. 2) [11,22]. A micropipette was used to insert 0.7 μL of 1% toluidine blue into the deepest portion of the internal compartment of the different implant systems to evaluate the sealing of the abutment/implant interface [31]. Care was taken to avoid contact between the dye solution and the internal threads of the implant systems [31]. The abutments (UCLA and flexcone) were attached to their corresponding implants, and the retention screws were tightened in a clockwise direction with a digital torque driver (DSP Biomedical, Campo Largo, PR, Brazil) according to the manufacturer’s recommendations. In the experimental EHU, MTU, and MTF groups, a single drop of the anaerobic sealing agent (Loctite 2400; Henkel Ltda, Düsseldorf, Germany) (Fig. 3) was applied to the retention screws [32]. A torque of 30 N·cm was applied to the EHU and MTF abutments using a digital torque wrench (Norbar Torque Tools Ltd, Mahape, Navi Mumbai, India), in accordance with the manufacturer’s recommendations. A torque of 20 N·cm was applied to the MTU abutments, as well as to the titanium cylinder retention screws of the flexcone abutment, in accordance with the recommendations of the manufacturer. After 3 min, the torque application was repeated for each retention screw [15,33]. The specimens were then stored at 37 °C and 100% relative humidity for 72 h to promote the complete polymerization of the anaerobic sealing gel [34].

2.2. Mechanical cycling
The specimens underwent mechanical cycling with an electromechanical machine to simulate masticatory fatigue (MSFM, ELQUIP, Sao Carlos, SP, Brazil) [35]. The mechanical cycling was conducted under dry conditions, with no distilled water, to avoid interference in the dye release. A loading force of 130 ± 10 N was applied at 2 Hz for 1 × 10⁶ cycles (Fig. 2) [12,36-38]. A semicircular metallic loading indenter (4 mm in diameter) was positioned on the occlusal side of a metallic device coupled to the UCLA and flexcone cylinders to simulate a crown, in accordance with the ISO 14801 standard (Fig. 2) [39]. The metallic indenter was previously lubricated (Graxa Azul Universal, FBS Lubrificantes Especiais, Araçoiaba da Serra, SP, Brazil) to reduce friction [12]. The specimens were fixed in a machine with hot glue at the bottom to avoid movement during mechanical testing [12].

2.3. Dye release analysis
After mechanical cycling, the specimens were removed from the polyurethane resin because the porosity of the material could influence the analysis of dye release. The implants were cleaned with a steel brush to remove any resin residue in the implant threads. The specimens were then stored in 400 μL of distilled water in Eppendorf tubes at 20 °C ± 2 °C for 1, 3, 6, 24, 48, 72, 96, and 144 h [31,40]. After each storage period, 200 μL of the solution was collected from each specimen and transferred to a 96-well microplate for spectrophotometry analysis (BioTek Instruments, Winooski, VT, USA) at a wavelength of 465 nm to measure the absorbance concentration.
ratio [31]. A calibration curve was generated by placing toluidine blue dye increments of 0.1 μL into 400 μL of distilled water, and the absorbance was recorded until 0.7 μL of the dye was reached (Fig. 4 and 5) [31]. After each spectrophotometry measurement was complete, the solution was returned to the Eppendorf tube. Dye release analysis data were used to evaluate the effectiveness of sealing the abutment/implant interface.

2.4. Preload maintenance analysis

After the dye release analysis, the specimens were embedded into a polyurethane resin. The reverse torque was measured using a digital torque wrench (Norbar Torque Tools Ltd, Mahape, Navi Mumbai, India) and then calculated as a percentage using the following formula:

\[
\text{Reverse Torque (\%)} = \frac{\text{Reverse torque value}}{\text{Torque value}} \times 100
\]

2.5. Statistical analysis

Data were assessed for normality using the Shapiro-Wilk test. Reverse torque was analyzed using 2-way repeated measures analysis of variance (ANOVA), while dye release was analyzed using 3-way repeated measures ANOVA. The Tukey least significant difference test (α=0.05) was also used for both analyses.

3. Results

The results of the 2-way measures ANOVA for reverse torque are shown in Table 1. All experimental groups demonstrated higher reverse torque values than the control groups (P < 0.001) (Table 2). The EHU and MTU control and experimental groups showed lower reverse torque values than the MTF control and experimental groups (P < 0.001). The EHU and MTU control groups exhibited a decrease in reverse torque values compared with insertion torque values in the same groups. However, the EHU, MTU, and MTF experimental groups exhibited higher reverse torque values than the insertion torque for the same groups, as well as the insertion torque for the MTF control group.

The results of the 3-way repeated measures ANOVA for dye release are shown in Table 3. Dye release analysis revealed no statistical difference between the control and experimental groups in all evaluated periods (Table 4); a notable exception was the MTF control group, which showed a lower dye release after 96 h, compared with dye release in the EHU and MTU control groups (P < 0.023). The EHU experimental group showed a higher dye release after 24 h compared with dye release in the MTU test group (P = 0.028). Comparing the control and experimental groups for each period, no differences were observed, with the exception of the EHU groups after 6 h (P = 0.006) and 24 h (P = 0.016). In intragroup comparisons over time, all evaluated groups showed statistically significant differences in dye release (P < 0.05), with the exception of the MTF control group, which showed no differences among the evaluated periods (P > 0.05).

4. Discussion

The null hypothesis was partially rejected because the sealing agent influenced the preload maintenance after mechanical cycling (Tables 1 and 2). However, no differences in the sealing of the abutment/implant interface were found after mechanical cycling (Tables 3 and 4).

The results of this study showed that the sealing agent resulted in satisfactory reverse torque values (Table 2) in all experimental groups under the sealing agent action. The EHU experimental group showed an increase of 26.31% of the initial torque applied on the retention screw, compared with that of the EHU control group (Table 2). The sealing agent was particularly effective in the MTF experimental group, with a mean reverse torque of 46.51 N·cm (Table 2). In the clinical setting, higher preload values facilitate avoidance of retention screw loosening, thereby preserving the screw-retained and cemented implant-supported prostheses [12,22].

Higher reverse torque values might have occurred because the sealing agent could absorb vibrations from the mechanical cycling [32], uniformly distributing the force to the walls of the components, and promote greater stability within screw-retained connections. Moreover, friction between parts is a primary cause of energy loss; thus, higher preload values might have been obtained by lowering the friction coefficients between connecting surfaces [20]. In addition, the sealing agent acts as a lubricant by reducing the friction between metal structures, owing to the viscosity of the sealing agent; this reduced preload loss [32].

Cashman et al. affirm that the incidence of reverse torque decrease in clinical situations varies from 0% to 13% [41]. The reverse torque values of the EHU and MTU control groups were lower than the initial torque values applied and the clinically acceptable values. The MTU control group showed a reduction of 24.61%, while the EHU control group showed a reduction of 19.46%. These results are in accordance with previous studies regarding preload values [10,12,20,21,35,42], in which the lowest preload values were attributed to the sedimentation mechanism [20]. In this mechanism, energy is released as irregular surfaces are threaded [2,20], resulting in immediate partial loss of applied torque. In addition to the effects of sedimentation, damage was caused by the irregular distribution forces in the EHU and MTU control groups after mechanical cycling, which led to the vibration of components and the sliding of threads in the opposite direction [15,43], thereby promoting lower reverse torque values. Furthermore, the samples were stored in distilled water for 144 h, which could influence screw loosening and the effectiveness of the sealing agent. According Duarte et al., penetration of oral fluids into microgaps formed in the implant/abutment connection can be responsible for the corrosion of structural material, including abutment screws, promoting the low friction between the threads, thereby decreasing the torque of the implant/abutment connection [44].

There was no decrease in the reverse torque value in the MTF control group after mechanical cycling, likely because a uniform distribution occurred in the two retaining screws as the flexcone-retaining screw was attached to the abutment; this may have resulted in a thicker screw and better system stability [33]. Moreover, a satisfactory adaptation between the Morse taper implant and flexcone abutment likely promoted a better force distribution [33], thereby reducing the overload on the retaining screw. This might have contributed to the lower release of dye in the MTF control and experimental groups (Table 4).

Sealing of the abutment/implant interface was analyzed through spectrophotometry; the data revealed dye release in all groups and periods evaluated, with the exceptions of the MTF control and experimental groups (Table 4). These findings were consistent with those of Rimondini et al. [45] and Proff et al. [46] These results may be directly related to the application of mechanical cycling [47] and the various connections and abutments involved [17,48], suggesting that these systems may be unable to prevent microleakage through the abutment/implant interface. Gaps at the abutment/implant interface due to inaccurate machining of one or both
Table 1. Two-way ANOVA for reverse torque analysis.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abutment/Implant</td>
<td>2</td>
<td>1617.185</td>
<td>808.592</td>
<td>10468.241</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Sealing Protocol</td>
<td>1</td>
<td>.005</td>
<td>.005</td>
<td>.605</td>
<td>.4395</td>
</tr>
<tr>
<td>Abutment/Implant x Sealing Protocol</td>
<td>2</td>
<td>.007</td>
<td>.004</td>
<td>.476</td>
<td>.6234</td>
</tr>
<tr>
<td>Residual</td>
<td>66</td>
<td>.51</td>
<td>.008</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Mean ±standard deviation (%) of reverse torque values of retention screws according to the abutment/implant system and presence of sealing agent.

<table>
<thead>
<tr>
<th>EHU</th>
<th>MTU</th>
<th>MTF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>80.54 ±9.05 Bb</td>
<td>75.39 ±10.41 Bb</td>
</tr>
<tr>
<td>Experimental</td>
<td>126.31 ±19.64 Ab</td>
<td>101.32 ±15.79 Ac</td>
</tr>
</tbody>
</table>

Abbreviations: EHU - external hexagon implant + UCLA abutment; MTU - Morse taper implant + UCLA abutment; MTF - Morse taper implant + flexcone abutment.

Different letters (uppercase in column and lowercase in row) indicate statistically significant differences (P<.05).

Table 3. Three-way repeated measures ANOVA for dye release analysis.

<table>
<thead>
<tr>
<th>Category for Period</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abutment/Implant</td>
<td>2</td>
<td>2.779E-4</td>
<td>1.389E-4</td>
<td>.967</td>
<td>.3874</td>
</tr>
<tr>
<td>Sealing Protocol</td>
<td>1</td>
<td>8.874E-5</td>
<td>8.874E-5</td>
<td>.618</td>
<td>.4357</td>
</tr>
<tr>
<td>Abutment/Implant x Sealing Protocol</td>
<td>2</td>
<td>4.378E-4</td>
<td>2.189E-4</td>
<td>1.524</td>
<td>.2282</td>
</tr>
<tr>
<td>Subject (Group)</td>
<td>48</td>
<td>.007</td>
<td>1.436E-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category for Period</td>
<td>7</td>
<td>.003</td>
<td>4.477E-4</td>
<td>12.842</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Category for Period x Abutment/Implant</td>
<td>14</td>
<td>.001</td>
<td>5.101E-5</td>
<td>1.463</td>
<td>.1228</td>
</tr>
<tr>
<td>Category for Period x Sealing Protocol</td>
<td>7</td>
<td>2.499E-4</td>
<td>3.570E-5</td>
<td>1.024</td>
<td>.4137</td>
</tr>
<tr>
<td>Category for Period x Abutment/Implant x Sealing Protocol</td>
<td>14</td>
<td>.001</td>
<td>9.366E-5</td>
<td>2.687</td>
<td>.0009</td>
</tr>
<tr>
<td>Category for Period x Subject (Group)</td>
<td>336</td>
<td>.012</td>
<td>3.486E-5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Mean ±standard deviation (μl) of dye release according to the abutment/implant system and presence of sealing agent, and period of evaluation.

<table>
<thead>
<tr>
<th>Period</th>
<th>EHU Control</th>
<th>EHU Experimental</th>
<th>MTU Control</th>
<th>MTU Experimental</th>
<th>MTF Control</th>
<th>MTF Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hour</td>
<td>0.056 ±0.002 Ca</td>
<td>0.054 ±0.005 CDa</td>
<td>0.055 ±0.005 Ca</td>
<td>0.055 ±0.005 Aa</td>
<td>0.053 ±0.005 Aa</td>
<td>0.056 ±0.004 ABa</td>
</tr>
<tr>
<td>3 Hours</td>
<td>0.055 ±0.005 Ca</td>
<td>0.056 ±0.004 BCDa</td>
<td>0.055 ±0.003 Ca</td>
<td>0.055 ±0.004 Aa</td>
<td>0.056 ±0.006 Aa</td>
<td>0.057 ±0.003 Aa</td>
</tr>
<tr>
<td>6 Hours</td>
<td>0.056 ±0.03 Ca*</td>
<td>0.052 ±0.001 Da*</td>
<td>0.055 ±0.002 Ca</td>
<td>0.054 ±0.004 Aa</td>
<td>0.053 ±0.003 Aa</td>
<td>0.054 ±0.004 Ba</td>
</tr>
<tr>
<td>24 Hours</td>
<td>0.058 ±0.004 BCa*</td>
<td>0.063 ±0.005 Da*</td>
<td>0.055 ±0.003 Ca</td>
<td>0.056 ±0.005 Ab</td>
<td>0.057 ±0.004 Ab</td>
<td>0.060 ±0.005 Aab</td>
</tr>
<tr>
<td>48 Hours</td>
<td>0.058 ±0.005 ABCa</td>
<td>0.061 ±0.007 ABCa</td>
<td>0.056 ±0.005 BCa</td>
<td>0.060 ±0.005 Aa</td>
<td>0.055 ±0.005 Aa</td>
<td>0.058 ±0.007 ABa</td>
</tr>
<tr>
<td>72 Hours</td>
<td>0.063 ±0.007 ABa</td>
<td>0.066 ±0.007 Aa</td>
<td>0.063 ±0.005 Aa</td>
<td>0.052 ±0.017 Aa</td>
<td>0.058 ±0.012 Aa</td>
<td>0.063 ±0.001 Aa</td>
</tr>
<tr>
<td>96 Hours</td>
<td>0.064 ±0.005 Aa</td>
<td>0.063 ±0.009 Aa</td>
<td>0.065 ±0.006 Aa</td>
<td>0.055 ±0.018 Aa</td>
<td>0.054 ±0.013 Ab</td>
<td>0.065 ±0.013 Aa</td>
</tr>
<tr>
<td>144 Hours</td>
<td>0.059 ±0.005 ABCa</td>
<td>0.060 ±0.008 ABCDa</td>
<td>0.061 ±0.006 ABA</td>
<td>0.064 ±0.008 ABA</td>
<td>0.061 ±0.005 Aa</td>
<td>0.061 ±0.008 ABA</td>
</tr>
</tbody>
</table>

Abbreviations: EHU - external hexagon implant + UCLA abutment; MTU - Morse taper implant + UCLA abutment; MTF – Morse taper implant + flexcone abutment.

Different letters (uppercase in column, lowercase in row among abutment/implant systems for the same experimental condition, and asterisk between sealing protocols for the same abutment/implant system) indicate statistically significant difference (P<.05).
components may contribute to the results observed in this study [3,9]. This study indicates that the sealing agent contributed to the elevation of the reverse torque screw values, promoting a satisfactory stability of the abutment/implant assembly. This would be useful to prevent microleakage and microorganism incorporation into the implant/abutment connection area; however, it is important to consider the potential risk of the screw fracture and/or damage of the components when it has to be removed due to the elevation of reverse torque. Furthermore, it is necessary to emphasize that the screw loosening also works as the initial signs such as ill-fitness, unsatisfactory occlusion, and/or parafunction presence before severe failure occurs [9,12]. The manufacturer’s recommendation of the anaerobic sealing agent application is designed for the sealing and locking of screws that require normal disassembly using specific hand tools [49]. According to the EU Regulations No. 1272/2008, the substance itself is not nocive, and the post-curing process of the sealing agent is fully secure, once the agent is immovable [49]. Therefore, it is important to emphasize that the use of the sealing agent did not eliminate the reversibility characteristics of the assessed screw joints [22]. However, this study is characterized as an in vitro study; thus, complementary in situ and/or in vivo analysis of biocompatibility and cytotoxicity are required. Without the demonstration of the applicability of the sealing agent in clinical conditions by these future studies, the use of the same by clinicians cannot be condoned.

There were some notable limitations in the present study. First, only one sealing agent was tested; second, it is difficult to accurately simulate a clinical scenario in an in vitro study. Furthermore, the samples were affected simultaneously by the mechanical loading and dipping with different periods, influencing the conclusion whether tie lock is effective for microleakage and loosening. Further analyses regarding the use of a sealing agent during implant application are recommended, such as the evaluation of the physical properties of the sealing agent under multidimensional investigation, longitudinal evaluation of its biocompatibility, cytotoxicity, and solubility in oral fluids to establish a security protocol related to the frequency of attachment and detachment, removal of this material, and replacement.

5. Conclusion

Based on the results of the study, it can be concluded that the sealing agent provided effective preload maintenance of all abutment/implant systems evaluated in this study, and that in general, the sealing agent is a suitable alternative for sealing the Morse taper connection.

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Conflict of interest statement

The authors declare that they have no conflict of interest.

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