Evaluation of Removal Torque and Internal Surface Alterations in Frictional Morse Taper Connections After Mechanical Loading Associated or Not with Oral Biofilm

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Purpose: To evaluate the abutment removal torque and the morphologic aspects of wear in frictional Morse taper connections after axial loading with or without biofilm immersion. Materials and Methods: Thirty sets of Morse taper implants and prosthetic abutments were divided into six groups based on the number of mechanical loading cycles and immersion in biofilm derived from human saliva: without load, without biofilm; without load, with biofilm; 100,000 cycles of load, without biofilm; 100,000 cycles of load, with biofilm; 500,000 cycles of load, without biofilm; and 500,000 cycles of load, with biofilm. Mechanical loading was applied at a force of 80 ± 15 N with a frequency of 2 Hz for 100,000 or 500,000 cycles. After removal torque evaluation, the internal surface of the implants was evaluated by scanning electron microscopy and optical profilometer. The results were statistically analyzed at a significance level of $P = .05$.

Results: Overall, the removal torque increased for samples submitted to loading (100,000 cycles of load, without biofilm = 83.8 ± 15.8 Ncm; 100,000 cycles of load, with biofilm = 160.6 ± 16.2 Ncm; 500,000 cycles of load, without biofilm = 147.0 ± 29.3 Ncm; 500,000 cycles of load, with biofilm = 154.5 ± 14.0 Ncm) compared to samples without loading (without load, without biofilm = 23.0 ± 9.4 Ncm; without load, with biofilm = 27.2 ± 7.5 Ncm). The removal torque was not different between groups that received the same number of loading cycles and varied on biofilm exposure ($P > .05$). However, samples immersed in biofilm showed higher values of removal torque. Surface analysis revealed that the damage on the internal surface of implants was lower in samples not submitted to cyclic mechanical loading ($P < .05$) independently of immersion in biofilm medium. Conclusion: Cyclic mechanical load on the frictional implant-abutment connection of Morse taper implants increased the removal torque of abutments. The findings of this research suggest that the presence of biofilm can potentially increase the removal torque in frictional Morse taper connections, although more studies are recommended to support this affirmation. Oral biofilm did not interfere with the presence of wear areas along the internal surface of Morse taper implants but increased the roughness values. Int J Oral Maxillofac Implants 2021;36:492-501. doi: 10.11607/jomi.8483

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In Morse taper implant systems, frictional contact between the conical surfaces of the internal part of the implant and the external part of the abutment produces union and stability at the implant-abutment connection.1 Morse taper implants have an internal tapered angle with up to 6 degrees of divergence at the prosthetic connection level. Friction plays an essential role in this type of connection, and a wide contact area between the two adjacent surfaces, the internal surface of the implant, and the external surface of the abutment, is required. Therefore, the diameter of the abutment is slightly larger than the implant hub, which causes friction resistance at the implant-abutment interface after abutment activation.2 Hence, the reduced tapered angle results in high contact pressure and cold welding effect,3 culminating in a tight frictional junction in the implant-abutment connection.

The axial movement of the abutment into the implant hub occurs in two stages in Morse taper connections: first, at the time of abutment activation, and second, at the time of functional loading. In the oral
environment, mastication exerts a wedge effect and settling of the abutment, increasing friction and anti-rotational stability in conical connections. However, load application can cause wear of the surfaces at the implant-abutment connection as a consequence of plastic deformation. A long period of mastication could result in a decrease of the implant integrity and aggravate the deformation of structures. Since wear resistance is related to the mechanical characteristics of the materials involved in the system, implants made of titanium alloy can be damaged during the axial movement of stainless steel abutments due to a difference in the elastic modulus. Titanium alloy has approximately 110 GPa of elastic modulus, while stainless steel has > 200 GPa, indicating a high probability of wear in titanium alloy implants.

Considering that mastication causes wear and degradation of implant materials, the likelihood of microgap formation at implant-abutment connections is high. Moreover, recurrent mechanical load leads to micromovements of the prosthetic abutment, which can facilitate bacterial leakage through the pumping effect. Although Morse taper connections have demonstrated a reduction in abutment micromovement in comparison to external/internal hexagon systems, they do not eliminate microgap formation. Microgaps can act as bacterial reservoirs, impacting the long-term biologic success of the implant treatment. Even the biologic width formation around implants is influenced by the microgap.

The colonization of the internal part of the implant generates malodor and can potentially progress to infections in the peri-implant region. Furthermore, it is a hard-to-treat condition, once the access for decontamination is difficult and the oral biofilm cannot be eliminated by the immune system. In addition, biofilm can decrease friction, which harms the implant-abutment stability.

Although titanium has corrosion resistance due to the formation of a protective oxide (TiO₂) layer within 5- to 6-nm thickness, its wear resistance is low. This passive layer is not stable, especially under dynamic conditions such as mechanical loading, and chemo-mechanical variations have a negative influence on its integrity. In this context, the oral cavity is a complex biologic organ that undergoes repetitive chemo-mechanical changes. Moreover, saliva is a natural lubricant of the oral cavity rich in lipopolysaccharides, molecules of fundamental importance in biofilm formation. Worn and degraded surfaces are susceptible to additional wear in the presence of lipopolysaccharides. After titanium oxide passive layer destruction, lipopolysaccharides accelerate titanium corrosion by ion exchange between saliva and the new titanium surface. Studies have reported these results on screw-retained Morse taper and hexagonal implant connections. However, to the best of the authors’ knowledge, no other study has investigated wear in the presence of biofilm in frictional Morse taper connections. Therefore, the purpose of this study was to evaluate the removal torque and the morphologic alterations in the internal surface of frictional Morse taper connections after cyclic mechanical loading associated or not with oral biofilm.

**MATERIALS AND METHODS**

**Sample Preparation**

Thirty sets of 3.8 x 13-mm titanium alloy (Ti6Al4V, ELI, Grade 5) Morse taper implants (Arcsys System, FGM Dental Group) and stainless steel (18Cr14Ni2.5Mo) Morse taper abutments (3.5 x 2.5 x 6 mm) were used in this study (Figs 1a to 1c). The dental implants had a conical macrogeometry and a microroughness surface produced by the double acid-etching method. Implants were embedded in transparent acrylic resin (Clássico) using a plastic mold with 25 x 20 mm. A positioning instrument with a vertical guide was used to standardize
all samples in an accurate upright position. The platform of implants had 1 mm of space above the level of the acrylic resin to provide enough space for biofilm. To simulate the biomechanical characteristic of the maxillary trabecular bone, acrylic resin with an elastic modulus of approximately 4 GPa, close to the maxillary cancellous bone (1 to 10 GPa), was used in this study.22 After hardening of the acrylic resin blocks, samples were fixed in a metallic holding device to avoid oblique loads during abutment frictional activation. A specific mallet recommended by the implant system was used to activate abutments on the implants through three taps.

**Biofilm Growth**

Five mL of human saliva from two healthy individuals of 20 and 31 years of age were obtained and diluted (1:5) in culture medium (Tryptic Soy Broth [TSB], Sigma-Aldrich). These solutions were incubated for 48 hours at 35°C and further measured for the optical density by spectrophotometry (BioTek). The optical density at 630 nm was approximately equal to 0.5 McFarland Standard.23 Volunteers obtained saliva 2 hours after tooth brushing by spitting carefully in collection tubes. Individuals for saliva collection were in good dental and oral health, with no history of antibiotic treatment during the previous 6 months.

**Mechanical Cycling and Biofilm Immersion**

Six groups of five samples each were formed based on the number of loading cycles and biofilm immersion. Two groups were not submitted to mechanical cycling and were considered control groups. Samples of the first group only received abutment activation (without load, without biofilm), while samples of the second group received abutment activation and were immersed in biofilm for 72 hours (without load, with biofilm). Further groups received axial load in a pneumatic mechanical cyclic loading machine (Biocycle V2, Biopdi) at a frequency of 2 Hz; two groups were submitted to 100,000 cycles, and another two groups were submitted to 500,000 cycles. Samples of two groups, one of 100,000 cycles and one of 500,000 cycles, were immersed in biofilm for 72 hours before mechanical load application and were maintained with biofilm during cycling (Fig 1d). Each sample submitted to mechanical load received a force of 80 ± 15 N, which is in the range of physiologic load during chewing.24 Biofilm medium was replaced every 4 hours for groups with biofilm immersion.

**Removal Torque Evaluation**

A digital torque wrench (Lutron TQ8800, Lutron) was employed to measure the removal torque of the abutments. One examiner (H.Y.A.) was responsible for removal torque evaluation, and no calibration was necessary. Each of the implant-abutment assemblies was placed in a metallic support to avoid oblique loads during countertorque measurement. Removal torque was measured in samples without mechanical load after 72 hours. The removal torque of the samples submitted to mechanical load was measured after cycling.

**Wear Analysis**

After removal torque evaluation, samples were washed in an ultrasonic bath containing 70% isopropyl alcohol for 10 minutes and dried at room temperature. Prior to roughness evaluation, samples were washed in an ultrasonic bath containing 70% isopropyl alcohol for 10 minutes and dried at room temperature. Roughness values were measured in three regions (border, middle, and apical third) of each sample. Two parameters, arithmetic roughness (Ra) and maximum peak-to-valley distance (Rt), were analyzed in an optical profilometer (DektakXT, Bruker) with the following settings: 1-mm length, cut at 0.25 mm, and speed at 30 mm/s.

**Statistical Analysis**

The statistical analysis was carried out in the software Statistical Package for the Social Sciences (IBM SPSS 21.0). Data were analyzed by the Kruskal-Wallis test with Dunn test for multiple comparisons considering a significance level of 5% (P = .05).

**RESULTS**

**Removal Torque**

Comparisons between the groups without load, with or without biofilm, showed no statistically significant difference (P > .999). Groups with 100,000 cycles of mechanical load showed higher removal torque values compared to groups without load, but only statistically significant to the group with biofilm exposure (P = .008, without load, without biofilm vs 100,000 cycles of load, with biofilm; P = .024, without load, with biofilm vs 100,000 cycles of load, with biofilm). An increase in removal torque values was detected in samples of the groups 100,000 cycles of load, with biofilm, which were almost two times of the 100,000 cycles of load, without biofilm; however, they were not statistically significant (P = .905). The removal torque of the groups with 500,000 cycles of mechanical load was significantly higher than the group without load, without biofilm (P = .029, without load, without biofilm vs 500,000 cycles of loading, without biofilm;
Asmarz et al

Table 1 Data of Means, SD, Minimum Values, Maximum Values, and Medians of the Removal Torque Evaluation in Newton Centimeter (Ncm) Recorded on Frictional Morse Taper Connections

<table>
<thead>
<tr>
<th>Groups</th>
<th>Samples (n)</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without load, without biofilm</td>
<td>5</td>
<td>23.0</td>
<td>9.4</td>
<td>13</td>
<td>32</td>
<td>26ac</td>
</tr>
<tr>
<td>Without load, with biofilm</td>
<td>5</td>
<td>27.2</td>
<td>7.5</td>
<td>17</td>
<td>35</td>
<td>30ac</td>
</tr>
<tr>
<td>100,000 cycles of load, without biofilm</td>
<td>5</td>
<td>83.8</td>
<td>15.8</td>
<td>67</td>
<td>106</td>
<td>82bcd</td>
</tr>
<tr>
<td>100,000 cycles of load, with biofilm</td>
<td>5</td>
<td>160.6</td>
<td>16.2</td>
<td>133</td>
<td>175</td>
<td>162bcd</td>
</tr>
<tr>
<td>500,000 cycles of load, without biofilm</td>
<td>5</td>
<td>147.0</td>
<td>29.3</td>
<td>105</td>
<td>175</td>
<td>142bcd</td>
</tr>
<tr>
<td>500,000 cycles of load, with biofilm</td>
<td>4</td>
<td>154.5</td>
<td>14.0</td>
<td>145</td>
<td>175</td>
<td>149bcd</td>
</tr>
</tbody>
</table>

Different letters after medians represent significant differences between groups at \(P < 0.05\).

Fig 2 Scanning electron micrographs of Morse taper implant before abutment connection. (a) Detail from border to apical internal surface of implant; magnification of 40x. (b) Detail of an intact internal surface; magnification of 130x.

Fig 3 (a) Scanning electron micrographs of a sample from the group without load, without biofilm, after abutment removal, magnification of 30x. (b) Trivial wear area of the apical part of the implant internal surface; magnification of 95x. (c) Detail of the wear marks; magnification of 500x.

Fig 4 (a) Scanning electron micrographs of a sample from the group without load, with biofilm, after abutment removal; magnification of 40x. (b) Sparse wear areas along the implant internal surface, magnification of 100x. (c) Detail of the wear marks; magnification of 100x.

\(P = 0.025\), without load, without biofilm vs 500,000 cycles of loading, with biofilm). Differences between groups submitted to mechanical load were not statistically significant, independently of the number of cycles (\(P > .999\)). One sample of the group 500,000 cycles of loading, with biofilm was excluded from this study because it did not show any removal torque value or surface alteration due to a misfit at the time of abutment activation.

The data of means, SDs, minimum and maximum values, and medians of the removal torque evaluation are shown in Table 1.
Surface Analysis

All samples, with or without immersion in biofilm culture, revealed wear areas under SEM evaluation. Wear areas were observed as marks of abrasion on the internal surface of the implants. The difference of wear intensity was prominent in samples with a higher number of load cycles in comparison to groups that did not receive mechanical loading (Figs 2 to 8). Roughness evaluation between the groups without load, with or without biofilm, showed no difference in Ra and Rt values ($P > .999$). Roughness values of samples submitted to mechanical loading were higher than those without loading;
However, differences were only statistically significant with the samples submitted to 500,000 cycles of loading. Ra and Rt values of the group without load, without biofilm were lower than the groups with 500,000 cycles of loading, independently of the presence of biofilm, at all evaluated regions \((P < .05)\). For the group without load, with biofilm, the apical region of the implant internal part showed lower roughness values than those recorded on the group submitted to 500,000 cycles of loading, without biofilm \((P = .017, \text{Ra apical})\) or with biofilm \((P = .038, \text{Rt apical})\). Rt values in the border region of implants were statistically significant between the groups without load, with biofilm, and 100,000 cycles of load, without biofilm \((P = .040)\). Rt values in the border region of implants were also statistically significant between the groups without load, with biofilm, and 500,000 cycles of load, without biofilm \((P = .040)\). Differences between groups submitted to mechanical load were not detected, independently of the number of cycles (Figs 9 to 11).

**DISCUSSION**

This study assessed the removal torque and wear of frictional Morse taper connections of dental implants after cyclic axial loading in association with oral biofilm. The findings demonstrated that the removal torque increased for the samples with axial load compared to the samples without mechanical load. However, samples that received axial load and were simultaneously immersed in biofilm showed no difference in the removal torque compared to samples with the same number of loading cycles without biofilm immersion. This information is controversial in the literature since studies have demonstrated that removal torque can increase or decrease in Morse taper implants with biofilm immersion and simultaneous axial cyclic loading. The reason for this disagreement is not clear, but many factors such as different biomechanics of the implant systems, amount of biofilm, and elastic properties of materials are possible elements that can influence the removal torque outcome.

Abutment retention in screw-retained Morse taper systems comes from friction between the screw and the internal surface of the implant. On the other hand, the abutment of frictional Morse taper systems is stabilized by the reduced tapered angle at the implant-abutment connection, which allows a tight frictional contact between the internal surface of the implant and the external surface of the abutment shaft. A systematic review showed that the hermetic seal is not achievable in any of the implant systems, although Morse taper connections were superior compared with other implant-abutment systems.
Fig 10 Box plots showing the medians, quartiles, and extreme values of roughness parameters at the middle part of the internal surface of Morse taper implants. Groups with 500,000 cycles of load showed a difference in Ra values compared to the group without load, without biofilm ($P = .007$), without load, without biofilm vs 500,000 cycles of load, without biofilm; $P = .023$, without load, without biofilm vs 500,000 cycles of load, with biofilm). Significant differences were also found in Rt values between groups without load, without biofilm vs 100,000 cycles of load, with biofilm ($P = .027$), without load, without biofilm vs 500,000 cycles of load, without biofilm ($P = .005$), and without load, without biofilm and 500,000 cycles of load, with biofilm ($P = .020$).

Fig 11 Box plots showing the medians, quartiles, and extreme values of roughness parameters at the apical part of the internal surface of Morse taper implants. Ra values were significantly higher in groups with 500,000 cycles of load compared to the group without load, without biofilm ($P = .005$), without load, without biofilm vs 500,000 cycles of load, without biofilm; $P = .030$, without load, without biofilm vs 500,000 cycles of load, with biofilm). Differences were also detected in Ra values between groups without load, with biofilm vs 500,000 cycles of load, without biofilm ($P = .017$). Significant differences were found in Rt values between groups without load, without biofilm vs 500,000 cycles of load, without biofilm ($P = .012$), without load, without biofilm vs 500,000 cycles of load, with biofilm ($P = .006$), and without load, with biofilm vs 500,000 cycles of load, with biofilm ($P = .038$).
When two metallic surfaces are in close contact with a trapped thin layer of liquid, a strong adhesion between the structures is achieved; the thinner the liquid layer, the stronger the adhesion. Thus, theoretically, besides the impact of axial mechanical load and friction, the adhesion resulting from liquid surface tension increases the removal torque in samples immersed in biofilm. In the present study, however, this hypothesis could not be proven.

In frictional Morse taper systems, repeated loading cycles intensify wedging, which not only prevents abutment loosening after insertion but also increases the required force for abutment removal. Nevertheless, the higher the number of loading cycles, the lower the removal torque increases. A study demonstrated that deeper insertion of the abutment in the tapered interface does not lead to a continuous increase in removal torque or pull-out force. The findings of the present study corroborate with this interpretation since the removal torque followed an ascending trend based on the number of mechanical cycles but with a limited range. More studies are suggested to establish a threshold of whether the cyclic loading contributes to implant-abutment overlap and interface sealing.

Overall, wear analysis revealed that oral biofilm does not modify the wear rate and roughness values along the internal surface of frictional Morse taper connections. Nevertheless, the damage at the internal surface of the implants was somehow reduced in samples immersed in biofilm medium during cyclic axial loading. When compared to groups with 500,000 cycles, samples of the group without load and without biofilm consistently showed lower Ra and Rt values; however, this difference in roughness values was not always present in samples of the group without load and with biofilm. Likewise, for removal torque evaluation of groups without mechanical load compared to those with 500,000 loading cycles, samples immersed in biofilm showed higher values than those without biofilm immersion. Simultaneous biofilm immersion and mechanical loading in tapered systems may have a synergistic effect on deeper insertion of the abutment on the implant hub due to the lubrication of biofilm. This fact may explain why the removal torque value increases in the presence of biofilm.

On the microscopic scale, even machined surfaces have some irregularities and asperities. Thus, implant and abutment surfaces are not entirely in close contact. When two solid surfaces are in close contact, mechanical degradation of one or both surfaces is inevitable during sliding motion. The wear occurs due to attrition force on contact points such as irregularities and asperities, producing plastic deformation in these areas, and bringing the sliding surfaces closer together. Axial loading generates vertical micromotion in the implant-abutment connection, inducing friction through the wedging effect, and a protective effect against horizontal micromotion. However, micromovements can deteriorate the titanium oxide layer, causing material loss and uncovering the mass material, which is more vulnerable to wear in the presence of biofilm, and facilitate the penetration of oral biofilm through pumping effect. Moreover, cyclic mechanical load disposes the materials to repetitive stress and material loss, which is called fretting wear. Even though oral biofilm may reduce micromovements and the frictional wear of materials, bacterial metabolites such as lipopolysaccharides would deteriorate titanium alloy through a synergistic effect of wear and chemical corrosion of titanium implants.

The findings of the present study on the wear of titanium-based implants after cyclic mechanical load suggest that oral biofilm may interfere with wear areas and roughness values along the internal surface of frictional Morse taper connections. If the findings of the present study are related to those of others, a study with 10 Morse taper implants showed abutment torque loss and damage to the implant internal surface in samples immersed in biofilm medium after screw-retained abutment connection without mechanical loading. In another in vitro investigation, 60 Morse taper and external hexagon implants were submitted to 500,000 cycles of mechanical load after 72 hours of biofilm immersion. Microgap size was significantly lower in samples without mechanical loading, and more biofilm penetrated into the implant-abutment connection in external hexagon than Morse taper joints, indicating a more tight union to the Morse taper connection. The consequence of wear in dental implants is the tribocorrosion, a chemo-mechanical degradation process in which particles from titanium surfaces are released in the oral environment, increasing tissue inflammation. The presence of metal particles and ions promotes degenerative changes in macrophages and neutrophils such as phagocytosed titanium microparticles, mutations in human cells cultured in medium containing titanium-based nanoparticles, and inflammatory cell influx in vitro. In this context, oral biofilm has a detrimental effect on peri-implant tissues since bacterial colonization may accelerate the chemical corrosion of metallic surfaces and activate the host inflammatory response, stimulating peri-implant pathologic bone resorption.

This study has limitations to be acknowledged. Different factors such as taper angle, contact length, material characteristics, coefficient of friction, biofilm in the implant-abutment interface, presence of microgaps, insertion depth of the abutment, and dimensional misfits between the implant and abutment in the Morse taper connection can affect the removal torque and...
wear. Further, acrylic resin was used to reproduce bone in this study; however, from the materials point of view, bone is a composite structure with 70% ceramic hydroxyapatite and 30% polymeric fibers. Therefore, the present in vitro study only showed a limited aspect of the issue, and the findings should be interpreted cautiously. In addition, mechanical cycling only simulates patient chewing; however, it did not reproduce all movements performed during mastication, which is probably much more complex. Moreover, the interaction between host-response and bacterial invasion should be evaluated in a clinical scenario since it cannot be mimicked in laboratory experiments. Future research could evaluate the presence of biofilm at the internal connection surfaces by SEM observations to confirm whether the biofilm is successful in colonizing the frictional implant-abutment interface of Morse taper implants in this in vitro model. The electrochemical stability of the titanium surface after wear in contaminated conditions is another topic suggested for further investigations. Clinical studies are necessary to confirm if frictional Morse taper connections provide admissible torque maintenance over a long time in function.

CONCLUSIONS

Taken together, this study demonstrated that cyclic mechanical load on the frictional implant-abutment connection of Morse taper implants increases the removal torque of abutments and can cause wear on the implant internal surface. The findings of this research suggest that the presence of biofilm can potentially increase the removal torque in frictional Morse taper connections, although more studies are recommended to support this affirmation. Wear analysis revealed that oral biofilm did not decrease the wear marks along the internal surface of Morse taper implants. However, samples immersed in biofilm showed higher roughness values compared with groups not exposed to biofilm.

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