COMPARATIVE TRIBOLOGICAL STUDY OF TWO PROSTHETIC DENTAL MATERIALS: ZIRCONIA AND VITA ENAMIC

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Abstract: The purpose of this study was to compare the tribological behaviour of two commercial prosthetic materials – Zirconia and a polymer infiltrated ceramic (PIC) commercially known as VITA ENAMIC – when tested against human molars/premolars. Samples of both materials were prepared and their hardness, wettability and topography were characterised. Antagonist teeth samples were prepared by cutting human molars/premolars to obtain isolated cusps. A wear test was performed during 306,000 chewing cycles, corresponding to 1.5 year of mastication, using a simulator with artificial saliva as lubricant. The wear mechanisms were analysed by scanning electron microscopy (SEM), the dental wear loss was determined by volume calculation using 3D scans of the cusps, and the prosthetic material loss by 2D profilometry analysis. Contrarily to VITA, no wear was found in Zirconia. No correlation was found between dental wear and the used counter-face, showing that dental wear is not influenced by the counter-face hardness when opposing surfaces with similar roughness are used.

Keywords: tribology, Zirconia, Vita Enamic, wear, teeth, cusps.

1. INTRODUCTION

Prosthetic dental materials are synthetic components that can be used to replace, repair or rebuild missing teeth, aiming to re-establish the functionality of teeth and patient’s comfort. One of the most important goals in dental treatment is the development of restorative materials with ideal physical properties that do not compromise the aesthetic issues, which play a major role, and the functionality and health of teeth. For this purpose, these materials must follow appropriate standards concerning mechanical resistance and optical nature [1–3].

For decades, metal-ceramic restorations were the option for orthodontic and prosthetic treatments. However, aesthetic limitations and concerns related to biocompatibility led to the development of metal-free materials. Nevertheless, there are concerns related to the materials’ abrasiveness against natural dentition under mastication cycles in oral environment. As a result of friction and wear this abrasiveness may cause the acceleration of enamel loss. Therefore, an adequate selection of restorative ceramic material is mandatory, in order to preserve the occlusal interactions and prevent a high rate on antagonistic tooth wear. This means that the wear rate of ceramics should match that of posterior tooth enamel [4–9].

Advanced ceramic materials such as Zirconia have shown to be appropriate substitutes for dental clinical applications. Zirconia has been used as an aesthetic restorative material for permanent teeth due to its excellent properties which include a high flexural strength, a superior fracture resistance and an ideal colour stability [10–13]. However, there are some concerns related to the high antagonistic tooth wear and loss of tooth structure due to the abrasive properties of Zirconia which is significantly harder (10–12 GPa) than enamel (<6 GPa) [14–16].

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New restorative materials have been developed aiming a more realistic mimicking of the natural dental materials. These materials include polymer-infiltrated-ceramics (PICs) with a dual network structure, and consist in porous ceramics infused with polymers. According to J. Min. et al., PICs have mechanical properties that are superior to those of pure ceramic, enabling stability against mastication stresses [17, 18]. PICs prevent the propagation of cracks, due to the interpenetration of polymer in the material. Despite having a better behaviour in terms of wear effect in the antagonist tooth, PICs present a higher wear compared to ceramic based materials [19, 20].

Studies that predict the clinical behaviour of newly engineered materials, like PICs, are scarce when comparing with those of ceramic based materials, such as Zirconia-based dental prosthetics. In this work, the performance of the prosthetic materials Zirconia and polymer infiltrated ceramic (PIC) known as VITA ENAMIC were compared and investigated in terms of tribological behaviour, using an equipment that mimics the chewing cycles.

2. EXPERIMENTAL PROCEDURE

Permanent premolars/molars human teeth were used in this work. They were sterilised with 1.0% chloramine-T trihydrate bacteriostatic/bactericidal solution for one week and then brushed with toothpaste and stored in distilled water at 4°C to minimise deterioration. Each tooth was sectioned into cusps and each section was fixed in an acrylic self-curing orthodontic resin so that ≈5 mm of the cusps was exposed. The cusps were characterised in terms of geometry using a 3D scanner (Small Milling Machine, Roland Modela MDX–20). The data was converted to STL files using Dr. Picza software and the resulting profiles were analysed using the three-dimensional Rhinoceros 5 software.

The prosthetic materials used were 5% Yttria-stabilised Zirconia (IPS e.max ZirCAD, Ivoclar Vivadent) and Vita Enamic® (VITA Zahnfabrik). Using a precision cutter equipment (Struers accutom 50, Struers Inc.), plates of each material were obtained. Heat treatment was conducted in Zirconia for sintering, according to the manufacturers’ instructions. Prepared samples were fixed in a thermosetting phenol formaldehyde resin. The samples were then polished using Silicon Carbide Substrates (SiC) of 320, 600, 800 and 2400 mesh. Finally, the prepared samples were washed in an ultrasonic bath.

To characterise both prosthetic materials, several tests were performed: wettability by the sessile drop method (Ramé-Hart, 100–07–00) using artificial saliva; surface roughness by atomic force microscopy (AFM Nanosurf Easyscan2); and hardness measures using the Vickers hardness tester (HSV–30 Shimadzu).

Wear tests were performed using a chewing simulator CS–4.2 (SD Mechatronik, FieldKirchen-Westerham, Germany). Prosthetic specimens were fixed in the bottom holders of each chamber with acrylic self-curing orthodontic resin and the antagonistic dental specimens were placed on top. Six samples of each prosthetic dental material were used.

The experimental conditions of the wear tests were established using the results of previous studies [21] and according with standard operating parameters of the equipment (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Experimental conditions.</th>
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<tr>
<td>Number of cycles</td>
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<td>Vertical speed</td>
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<tr>
<td>Cycle frequency</td>
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<td>Lateral speed</td>
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<td>Temperature</td>
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<td>Vertical movement</td>
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<tr>
<td>Saliva pH</td>
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<tr>
<td>Horizontal movement</td>
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<td>Weight per sample</td>
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To measure the wear loss of tooth specimens, each cusp was scanned before and after testing using a 3D scanner. The 3D images obtained were overlapped using the software Rhinoceros 5. The volume of the worn areas was estimated by the same 3D software. Wear losses of prosthetic materials after testing were estimated using a 2D profilometry (Mitutoyo SJ–2001). To assess the wear mechanisms, the samples were analysed by SEM (FEG–SEM JEOL JSM–7001F), being previously coated with a thin film of Au/Pd, providing to the samples a conductive layer.
3. RESULTS AND DISCUSSION

The results of wettability tests (contact angle), Vickers hardness (HV) and surface roughness (Ra) of prosthetic materials before wear simulation are shown in Table 2. The contact angle and the roughness of Zirconia and Vita Enamic were similar. However, a higher value of hardness was obtained for Zirconia comparing with Vita.

Table 2. Contact angle, surface roughness (Ra) and Vickers hardness (HV) of prosthetic materials. Mean ± STD.

<table>
<thead>
<tr>
<th>Material</th>
<th>Contact angle Θ (°), n = 20</th>
<th>Ra (nm), n = 6</th>
<th>HV, n = 10</th>
</tr>
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<tr>
<td>Zirconia</td>
<td>35 ± 1.6</td>
<td>21 ± 4</td>
<td>1241 ± 70</td>
</tr>
<tr>
<td>Vita Enamic</td>
<td>35 ± 1.9</td>
<td>18 ± 7</td>
<td>253 ± 29</td>
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No attainable differences were observed in wear of tooth specimens for the two tribological systems in study. However, there is a correlation between the radius of curvature (RoC) of the cusps and their corresponding volumetric loss (Figure 1). The wear decreases considerably for cusps with higher RoC values for both counter materials.

Figure 1. RoC dependant volumetric loss for antagonist cusps tested against Zirconia and Vita Enamic plates. Mean ± STD, n = 3.

However, prosthetic wear results were significantly different for the two tribological systems under study. Profilometry measurements of Vita plates showed wear tracks with depth between 170 µm and 500 µm and width between 1 mm and 2.5 mm (Figure 2 a). The wear rate for Vita plates was 0.48 ± µm²/cycle. However, for Zirconia plates, the wear loss was negligible compared with Vita Enamic (Figure 2 b).

Figure 2. Example of a 2D transversal wear profile on Vita Enamic (a) and Zirconia (b).
SEM images of Vita Enamic and Zirconia samples and antagonist cusps are presented in Fig. 3. For Vita Enamic, noticeable changes and wear were observed on the surfaces of the antagonistic tooth enamel (Figure 3 A), with striated wear grooves and scratches in the sliding direction (Figure 3 B). In particular, it was observed the presence of fragments pulled out from enamel surface (Figure 3 B –FP) due to the irregular concavities and gaps on worn surfaces. Additionally, Vita samples show strong stress signals and scratches in the sliding direction (Figure 3 C and D). Furthermore, it was observed areas of decohesion and abrasion (Figure 3 D dashed arrows and white arrows, respectively). Regarding the tests with Zirconia, the wear surfaces of enamel were generally smooth and no fractures were detected (Figure 3 E and F). No substantial surface changes or wear were found for the prosthetic material (Figure 3 G and H).

**Figure 3.** Representative SEM images of cusp surfaces (left – A, B, E and F) tested against the prosthetic materials PIC (Vita Enamic) and Zirconia (5Y–TZP) (right – C, D, G and H). * stands for abraded surface. FP stands for subsurface fatigue from surface of enamel. Black arrow corresponds to an artefact, white arrows indicate the observed scratches and dashed arrows indicate areas of decohesion in Vita Enamic.

Wettability is an important surface property relevant for prosthetic dental materials, which may affect the tribological properties at the micro and nanoscale [22]. Lower values of contact angle were obtained for both prosthetic materials, comparing with those reported in previous studies [23], which may be attributed to the use of artificial saliva instead of water as wetting liquid. According to A.Vissinket et al., artificial saliva contains surface-active components which are very likely to adsorb to the solid-liquid and the liquid-vapour interface, resulting in a decrease of the contact angle [24]. Also, the material’s surface roughness can influence the contact angle. Generally, the less irregular the material is in its surface (i.e. the lower is its core roughness), the lower the contact angle [25]. For this study, no observable differences in Ra were detected between Zirconia and Vita Enamic, which means that the influence of roughness on the results of contact angle is negligible.

The results obtained for wear behavior of prosthetic materials and tooth specimens are not directly comparable with those of previous studies, due to the great variety of experimental parameters used for chewing simulation performed in vitro. For this study, a two-body wear test was carried out to measure wear resistance of prosthetic materials and teeth when occlusal contact occurs between the counter-body and the antagonist. The wear of tooth specimens was detected by volumetric loss, which leads to a more consistent mean than weight loss analysis, whose values vary linearly over time [13]. As referred previously, a tendency was observed in wear behavior for both dental antagonists: the volumetric loss of the cusps decreases with the increase of tooth RoC. It is known that as the contact area increases, the compressive tension decreases [26]. This means that the area over which a force is exerted is inversely proportional to the tension which promotes strain and stress. Therefore, a higher contact area is associated to a higher RoC, which leads to minimization of wear phenomena.

Vita Enamic presents a hardness five times below the hardness of Zirconia but similar of human enamel, in agreement with what was found by other authors [18]. In addition, both materials differ in terms of toughness fracture, 1.5 MPa m$^{1/2}$ for Vita and 8–10 MPa m$^{1/2}$ for Zirconia [17, 27]. Thus, those differences can explain the higher wear resistance of Zirconia comparing with Vita Enamic as
observed in the SEM images which shows that wear of Zirconia is smaller. This would be expected, due to the physical properties of Zirconia in terms of hardness, toughness, flexural strength and density, and the fact that the addition of yttrium reinforces the crystal structure, preventing stress events in the material [13]. Nevertheless, it is evident that Vita Enamic caused greater abrasion on the antagonist than Zirconia. The polished surface of Zirconia causes the removal of material by abrasion to be relatively low. In fact, Zirconia ensures this phenomenon throughout the test while in Vita the roughness of contact zone increases [28]. However, despite the increased roughness on the surface of Vita during the wear test, the similar hardness between vita and the tooth may justify its low wear.

4. CONCLUSIONS
Concerning prosthetic wear:
1. No wear was observed for Zirconia.
2. Significant wear was found for Vita. The main wear mechanisms were polishing and pull out of ceramic part, due to the loss of adhesion with polymeric matrix.

For dental wear, it was found that:
1. The cusps wear is independent of the counter-face hardness.
2. The main mechanisms found were polishing for Zirconia and abrasion and subsurface fatigue for vita.

Although wear differences are found in the commercial prosthetic materials, no correlation was found between dental wear and the used counter-face, showing that dental wear is not influenced by the counter-face’s hardness when opposing surfaces with similar roughness are used.

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