Wear 297 (2013) 872–877

Contents lists available at SciVerse ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Effect of feldspar porcelain coating upon the wear behavior of zirconia dental crowns

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ARTICLE INFO

Article history:
Received 15 June 2012
Received in revised form
28 August 2012
Accepted 15 October 2012
Available online 6 November 2012

Keywords:
Sliding wear
Biotribology
Feldspar coating
Zirconia
Teeth

ABSTRACT

Opposing dental surfaces, both natural teeth and restoration materials, are submitted to wear. The effect of the presence of feldspar porcelain coating upon the wear properties of dental zirconia opposing human teeth was evaluated using pin-on-plate test geometry. Human molar cusps performed as pins, coated and uncoated commercial zirconia performed as plates. Tests were carried out at room temperature in citric acid solution during 21,600 cycles, using 1 Hz, 1.96 N and 5 mm amplitude. Wear loss was measured by weighing the cusps before and after testing. The material loss of the plates was assessed by profilometry. Surface roughness and hydrophilicity of the plates' surfaces were evaluated by roughness and contact angle measurements.

Results show higher mass loss for teeth tested against feldspar veneered plates, together with higher friction coefficient. No wear was detected on unveneered zirconia surfaces. Contact angle results show distinct affinity of veneered (25°) and unveneered zirconia (70°) surfaces towards distilled water.

Porcelain coating of zirconia dental crowns affects tooth/crown wear behavior, resulting in increased wear of both the artificial crown and the opposing natural teeth. Coating should therefore be avoided in occlusal crown surfaces.

1. Introduction

Dental prosthetic structures are used to replace missing tooth tissue after lesion, aiming to reestablish the masticatory, phonetic and esthetic functions of natural teeth. In the early 1990s yttrium oxide partially stabilized tetragonal zirconia (Y-TZP) was introduced as a core material for all-ceramic dental restorations [1]. Due to the transformation toughening mechanism, Y-TZP presents mechanical properties superior to any other all-ceramic system, with reported *in-vitro* flexural strengths of 900–1200 MPa and fracture toughness of 9–10 MPa [1,2]. Y-TZP is also characterized by appropriate esthetic properties, low thermal conductivity, low corrosion potential, good radiographic contrast and good biologic compatibility, resulting that it has been extensively used in clinical dental restorations [2–4]. Established applications are cores of all-ceramic crowns and bridges, veneers, posts, inlays, brackets, abutments, and implants [5–7], without constraints regarding the size of the denture element [4].

In order to fully resemble the color, shimmer and translucency of natural teeth, Y-TZP crowns are further coated with a colored veneering ceramic [8], frequently feldspar porcelains [2,9]. Commercially available veneering ceramics exhibit compositional and microstructural differences, but are manufactured to identical international standards in terms of mechanical properties (required minimum flexural strength of 50 MPa, according to ISO 6872, 1995 [8]). However both clinical practice and *in-vitro* testing have identified a frequent and typical failure pattern, associated with a thin veneering layer remaining upon the zirconia framework [10]. In fact, issues noticed in zirconia restorations failure studies are not related to framework integrity, but rather to chipping, delamination, wear and fracture of the veneering material, *e.g.* [2,8,10–12]. The bond between veneering ceramic and zirconia framework is thus the current subject of a number of comprehensive investigations, *e.g.* [1,4,8,10,12–14]. However, only few studies report the wear behavior of feldspar porcelain coatings [15–17], and to the authors' best knowledge none evaluates the effect of porcelain upon tooth/restoration wear.

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0043-1648/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.wear.2012.10.016

Dental wear is a natural and unavoidable physiological process [18,19], resulting from the fact that dental materials are submitted to the forces associated with mastication and to the chemical and thermal aggressive environment of the oral cavity. Mastication forces depend on the physical properties of food and on individual age, sex and muscle build; they can vary from 2 to 150 N, with a maximum of 450 N reachable at the molars [20]. Temperature in the oral cavity typically varies from 0 to 55 °C, depending on food and beverage intake [21]; this variation can occur within seconds, imposing thermal stresses to the denture. The incidence of stresses together with the relative motion of contacting surfaces results in tooth wear, particularly on the occlusal surfaces. Tooth wear has multi-factorial origin involving the interplay of abrasive, tribochemical and fatigue wear [18,20].

Understanding the friction and wear behavior of human teeth against available restorative materials is essential for improving dental treatment. Wear studies enlighten the clinical management of tooth wear, in the sense that they tutor on minimization of causal factors, while comparing new and traditional restorative dental materials for replacement of missing tooth tissue. In this context, the overall goal of the present work is to contribute to the understanding of the wear behavior of dental materials in the presence of porcelain veneer. It concerns evaluation of the effect of feldspar porcelain coating upon the wear behavior of zirconia dental crowns against natural teeth. The option for studying wear behavior in an acid medium is justified by the significant role played by the oral environment upon the tribological behavior of natural and restorative dental materials [20,22]. Exposure to acidic oral environment is commonplace as a result of worldwide increase in the consumption of soft drinks, fruit juices and sport drinks (pH 1–6) [22]. While normal saliva is neutral (pH 7), the oral cavity environment of individuals with particularly acidic diet can be as low as pH 3 [22]. Demineralization and dissolution is thus to be expected, causing pathological tooth wear.

2. Materials and methods

All materials were donated by Zirclab Dental Company. Zirconia plates with 2×2.8 cm were obtained from pre-sintered Y-TZP blanks (White Peaks, with 95%–ZrO_2, < 0.4%–Al_2O_3, 5%–Y_2O_3). The blanks were dry machined and sintered according to supplier's specifications. After sintering the unveneered plates were polished with silicone rubber and diamond paste, while veneered plates were manually coated with feldspar (Sakura Elephant Dental) and glazed. Human molars were cut perpendicularly into four parts with a precision diamond saw. Each cusp was mounted in acrylic resin with the occlusal surface facing out (Fig. 1). Tooth samples were not polished, aiming to keep the original occlusal surface.

The wear tests were carried out *in-vitro* in linear reciprocating sliding mode. Pin-on-plate test geometry (prototype, Fig. 1) was used, with human molar cusps as pins and plates of veneered and unveneered commercial zirconia. Before and after testing the pins were placed in an oven during 48 h at 35 °C, to guarantee the same level of hydration during weighing. Weight measurements were carried out using a high precision scale (Sartorius MC5, 1 μg accuracy). After weighing and before testing the cusps were immerged in distilled water to avoid sample dehydration.

Before testing cusps profiles were measured by profilometry (Mitutoyo Contracer CP-200); plates and pins morphology was evaluated by optical microscopy (OM) (Olympus BH2-UMA) and field emission gun scanning electron microscopy (FEG-SEM) (Jeol JSM-7001F). Plates were also characterized by roughness measurements (Mitutoyo Surftest-301); five measurements were taken at each plate for reproducibility assessment.

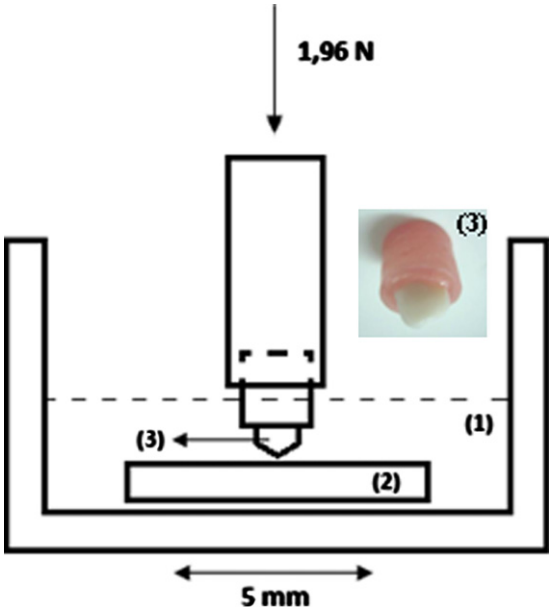

Fig. 1. Schematic representation of the wear test rig prototype: (1) citric acid solution, (2) zirconia plate, and (3) molar tooth cusp.

The hydrophilicity of the plates was determined by the sessile drop method using distilled water. Plates were previously cleaned with water and dried in vacuum oven during 24 h. Water drops of 4–6 μL were generated with a micrometric syringe and deposited on the plates' surface, inside a chamber previously saturated with water, at room temperature. Contact angle evolution was monitored during 600 s following drop deposition using a video camera coupled to a microscope (Wild M3Z) and to a frame grabber (Data Translation DT3155). Reported results correspond to the mean of at least five experiments.

Due to their geometric complexity, molar cusps were grouped in pairs with similar contact geometry. In each pair one cusp was tested against unveneered zirconia plate while the other was tested against feldspar veneered zirconia plate. Wear tests were carried out at room temperature under constant applied load of 1.96 N, 5 mm stroke and 1 Hz frequency, during a total number of 21,600 cycles (6 h). The test medium was a citric acid solution with pH value of 3.2; pH was measured before and after each test. The friction force was recorded during the test and the friction coefficient was determined.

One randomly chosen cusps pair was also characterized by X-ray microtomography (μ−CT) (Skyscan 1172), in order to evaluate the possibility of using this technique for wear volume loss determination. Scanning conditions were optimized elsewhere [23]. Samples were scanned at a voltage of 100 kV with current intensity of 100 μA. The spatial resolution was 6.76 μm on *xx* and *yy* axis, and 14 μm on *zz* axis. The radiographs were recorded at angles between 0° and 180° around the vertical axis, with 0.9 rotation step. Acquired image data were qualitatively and quantitatively interpreted using 3D tomographic reconstruction and analysis software, and the volume and length losses of the cusps after testing were estimated and compared with values obtained by weighing. For mass loss calculation a density of 2.5 g/cm^3 was assumed for the enamel [22].

The wear loss of the feldspar veneered zirconia plates was evaluated by 2D Laser profilometry (Mahr RM600) and the wear rate was estimated by dividing the wear track area mean by the total number of cycles. Worn surfaces were observed by OM and FEG-SEM coupled with energy dispersive spectroscopy microanalysis (EDS) (Oxford Instruments Inca pentaFETx3).