dental materials xxx (2018) xxx–xxx

Available online at www.sciencedirect.com

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Fatigue behavior of ultrafine tabletop ceramic restorations

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ARTICLE INFO

Article history:
Received 8 November 2017
Received in revised form
29 May 2018
Accepted 7 June 2018
Available online xxx

Keywords:
Ceramics
Mechanical stress
Fixed dental prosthesis
Fatigue test

ABSTRACT

Objective. The goal of this study was to investigate the fatigue life, failure modes, and stress distribution of partial ultrafine restorations for posterior teeth in different ceramics.

Methods. Sixty standard tabletop preparations in epoxy resin G10 received lithium-silicate-based zirconia-reinforced (ZLS) or hybrid ceramic (PIC) restorations in 0.5- or 1-mm thickness bonded with resin cement. The same cycling protocol was applied for all specimens, which consisted of 5000 cycles at 200 N, followed by 450-N cycles until the specimens' fracture or the suspension of the test after 1.5×10^6 cycles. Axial load was carried out with a 4 Hz frequency in Biocycle V2 equipment (Biopdi, São Carlos, SP), with samples immersed in water. The presence of cracks and/or fractures was checked every 2.5×10^5 cycles, and the survival analysis was performed with the number of cycles in which each specimen failed. All specimens were evaluated by stereomicroscopy and scanning electron microscopy (SEM). After data tabulation, Kaplan–Meier and Mantel–Cox (log-rank test) analyses were performed, followed by multiple pairwise comparison, all with a significance level of 5%, and Weibull analysis. Through three-dimensional finite element analysis, stress distribution and maximum principal stresses in the posterior occlusal veneers were evaluated by comparison of different types of substrate (G10, enamel/dentin, enamel), thicknesses, and ceramic materials.

Results. Zirconium-reinforced lithium silicate restorations with 0.5-mm thickness (ZLS.5) showed lower fatigue strength compared with that of 1.0-mm hybrid ceramic restorations (PIC1), and both were similar to other restorations (PIC.5 and ZLS1) (log-rank test, $\chi^2 = 11.2$; df = 3; $p = 0.0107 < 0.05$). ZLS groups presented random defects that culminated in fracture, whereas PIC groups presented defects that increased with mechanical fatigue after some cycling time. Stereomicroscope images show radial cracks due to the translucency of the material. There was no damage caused by the applicator. MPS (maximum principal stress) distributions were similar for the different substrate types, but the highest modulus of elasticity showed slightly lower stress concentration.

Significance. PIC is more likely to be used in thinner thickness than indicated by the manufacturer, with fatigue strength similar to that of thicker ZLS restorations.

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https://doi.org/10.1016/j.dental.2018.06.017
0109-5641/

1. Introduction

Preservation of tooth structure has always been a challenge for restorative dentistry [1]. For centuries, various techniques and materials have been developed to restore and reproduce dental structures [2]. Ceramics are vitreous materials, therefore friable, and thus, to play a role similar to that of a dental structure, must support masticatory forces without degrading [3]. The microstructure of ceramics significantly affects their behavior, so chemical composition, mechanical properties, laboratory processing type, thickness, and cementation method must be considered when the material type is selected. New minimally invasive restorative clinical approaches from a biomimetic perspective were facilitated by the evolution of metal-free ceramics and the advent of adhesive cementation [1,4], with materials that resemble natural tissues used for the repair of lost dental structures [5]. For the treatment of severe erosive lesions, ultrafine restorations adhesively cemented have been shown to be a conservative alternative to traditional onlays or total crowns in posterior teeth [6,7].

Various new types of ceramics, reinforced with more resistant materials like zirconia, have been developed, such as Vita Suprinity (ZLS, zirconia-reinforced lithium silicate), which has an elastic modulus closer to that of enamel, 65 GPa [8], and others with softer, polymer-like materials in their composition. Vita Enamic, for example (PIC, 14% organic polymer-infiltrated ceramic), is a hybrid material that combines ceramic and composite characteristics [9,10], presenting a low modulus of elasticity, closer to that of dentin, around 30 GPa [8]. Both materials can be found in CAD/CAM blocks and are indicated for partial posterior tooth restoration.

Good results in fracture resistance have been shown with the use of indirect monolithic ceramic restorations [11,12], which can be applied for partial preparation in posterior teeth, even in thin thicknesses [13], and are a good choice forworn dentition, requiring minimally invasive rehabilitation, restoring lost structures with minimal or no dental preparation [14,15].

Fatigue tests have been presented as an efficient method for the evaluation of the mechanical properties of long-term dental materials [3,16–18]. This type of test promotes the occurrence of chemical phenomena like slow crack growth, mechanical process degradation such as "hydraulic pumping", and internal friction in the walls of microcracks that occur in ceramic materials [18–21].

The purpose of this in vitro study was to evaluate the fatigue life of ultrafine, 0.5 and 1 mm, tabletop restorations for posterior teeth, in two different ceramics, a lithium silicate zirconia-reinforced (ZLS) and a hybrid ceramic (PIC), both adhesively cemented in a dentin-like material (G10).

2. Materials and methods

2.1. Specimen preparation

Sixty standard tabletop preparations with a simplified occlusal reduction corresponding to a lower second molar were milled in G10 fiber glass-reinforced epoxy resin (Protec, São Paulo, Brazil), a dentin-analogous material [22]. Specimens were embedded in acrylic resin cylinders (TDV, Pomerode, Brazil) 2 mm below the cement-enamel junction, and one master preparation was scanned (inLab SW4.2, SironaDental Systems GmbH, Bensheim, Germany). The information was sent to Cerec 3 software (v3.03, SironaDental Systems GmbH). Restorations were waxed in two occlusal thicknesses, 0.5 mm or 1.0 mm, and were also scanned. Vita Zahnfabrik blocks (Bad Säckingen, Germany) were milled to obtain restorations in Vita Suprinity with 0.5-mm (ZLS.5) or 1-mm thickness (ZLS1) or in Vita Enamic with 0.5-mm (PIC.5) or 1-mm thickness (PIC1). Restorations were cleaned in an ultrasonic bath with isopropyl alcohol for 10 min and dried. Following the manufacturer's instructions, milled Suprinity restorations underwent crystallization firing in a Vita Vacumat 6000 MP furnace (Vita Zahnfabrik). Polishing procedures were carried out with the respective commercial polishing kits (Vita Suprinity polishing set and Vita Enamic polishing set, bothVita Zahnfabrik). G10 preparations were randomly chosen and cleaned with 10% hydrofluoric acid (Condac porcelana, FGM Produtos Odontológicos Ltda, Joinville, Brazil) for 60 s, rinsed with air/water spray, and dried with oil-free air jets, after which a layer of the A + B adhesive system (Kuraray Noritake, Okayama, Japan) was applied by microbrush for 30 s, simulating a dental procedure. ZLS and PIC restorations were also cleaned in an ultrasonic bath and dried, after which the Clearfil Ceramic Primer (Kuraray Noritake) was applied for 60 s and light-cured. Panavia F 2.0 (Kuraray Noritake) resin cement was applied to internal restoration surfaces then seated in position with a 750-g apparatus; excess cement was removed with a microbrush, an air barrier was applied to cover the margins, and light polymerization was performed with Bluephase Style (Ivoclar Vivadent, Schaan, Liechtenstein) for 20 s on each surface. Cementation margins were finished and polished. All specimens were kept in 37 °C distilled water for 30 h prior to being tested.

2.2. Mechanical testing and reliability analysis

All specimens were subjected to the same cycling protocol. Axial loading was carried out at a frequency of 4 Hz in Biocycle V2 equipment (Biopdi, São Carlos, Brazil), with samples immersed in water. Specimens received an initial load of 200 N for 5000 cycles, followed by 450 N until failure, through a stainless-steel sphere with a 4.6-mm-diameter indenter centered with three-point contacts. Testing was limited to a maximum of 1.5×10^6 cycles and was interrupted every 2.5×10^5 cycles to check for the presence of cracks and/or fractures with the aid of adequate illumination and a stereomicroscope. An acetate strip was positioned between the applicator and the ceramic surface. The number of cycles until failure was recorded and used for survival analysis by Kaplan–Meier and Mantel–Cox tests (log-rank test), followed by multiple pairwise comparisons, all with a 5% significance level (GraphPad Prism version 7, La Jolla, CA, USA).

Failure probability was calculated for each time interval: 0–250,000, 250,000–500,000, 500,000–750,000, 750,000–1,000,000, 1,000,000–1,500,000, and 1,500,000–2,000,000 cycles (90% of bilateral confidence interval – Synthesis 9, Weibull ++ 9, Reliasoft). 2 parameter

Please cite this article in press as: Abu-Izze FO, et al. Fatigue behavior of ultrafine tabletop ceramic restorations. Dent Mater (2018), https://doi.org/10.1016/j.dental.2018.06.017