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Fatigue failure load of two resin-bonded zirconia-reinforced lithium silicate glass-ceramics: Effect of ceramic thickness

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ABSTRACT

Objectives. To evaluate the effect of ceramic thickness on the fatigue failure load of two zirconia-reinforced lithium silicate (ZLS) glass-ceramics, adhesively cemented to a dentin analogue material.

Methods. Disc-shaped specimens were allocated into 8 groups (n = 25) considering two study factors: ZLS ceramic type (Vita Suprinity — VS; and Celtra Duo — CD), and ceramic thickness (1.0; 1.5; 2.0; and 2.5 mm). A trilayer assembly (ϕ = 10 mm; thickness = 3.5 mm) was designed to mimic a bonded monolithic restoration. The ceramic discs were etched, silanized and luted (Variolink N) into a dentin analogue material. Fatigue failure load was determined using the Staircase method (100,000 cycles at 20 Hz; initial fatigue load ~60% of the mean monotonic load-to-failure; step size ~5% of the initial fatigue load). A stainless-steel piston (ϕ = 40 mm) applied the load into the center of the specimens submerged in water. Fractographic analysis and Finite Element Analysis (FEA) were also performed.

Results. The ceramic thickness influenced the fatigue failure load for both ZLS materials: Suprinity (716 N up to 1119 N); Celtra (404 N up to 1126 N). FEA showed that decreasing ceramic thickness led to higher stress concentration on the cementing interface.

Significance. Different ZLS glass-ceramic thicknesses influenced the fatigue failure load of the bonded system (i.e. the thicker the glass ceramic is, the higher the fatigue failure load will be). Different microstructures of the ZLS glass-ceramics might affect the fatigue behavior. FEA showed that the thicker the glass ceramic is, the lower the stress concentration at the tensile surface will be.

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1. Introduction

Nowadays, the concept of monolithic full-contour restorations using Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) technology has been considered as an alternative to the conventional restorative approaches for fixed dental prostheses (FDPs) [1]. This restorative alternative allows a substantial reduction of the ceramic thickness in accordance with the concept of minimally invasive dentistry, which emphasizes the use of high-resistance materials in association with adhesive luting techniques to restore teeth [2]. Thus, care must be taken in the minimum ceramic thickness required to ensure adequate mechanical performance, and for which information is not available in the literature.

Zirconia-reinforced lithium silicate (ZLS) glass-ceramics have been introduced into the dental market [1]. They consist of a new generation of ceramics, which allegedly combine glass-ceramic aesthetic performance and improved mechanical properties due to the presence of metasilicate and zirconia crystals into the glass matrix [3,4].

Currently, there are two different ZLS ceramic materials available for application in Restorative Dentistry, being both of them essentially composed by two crystal phases embedded into a glassy matrix. One of the crystalline phases consists of submicrometric lithium metasilicate (Li_2SO_3) crystallites in a round and slightly elongated shape, while the other is a lithium orthophosphate (Li_3PO_4) in a round shape with nanometric size [1]. According to Belli et al. [1], one of the major differences between the two materials is the size of lithium metasilicate crystals (Li_2SO_3 phase), which appears to have a bigger size in Celtra Duo (up to ~1 μm in length) than in Suprinity (~0.5 μm). Hence, theoretically it could be expected that different microstructures could affect the crack propagation and the fatigue behavior of the materials, as existing literature [5,6] stated that bigger grain sizes would lead to decreased mechanical performance in comparison to a material with same composition and smaller grain size.

When compared to the conventional lithium disilicate ceramic (without zirconia reinforcement), ZLS glass-ceramics present a lower percentage of crystal phase content (40–50% in comparison to 70% of a conventional lithium disilicate glass-ceramic) [4,7]. However, crystals within ZLS materials are smaller and the glassy matrix is reinforced due to highly dispersed zirconium dioxide (~10% in weight), which is assumed to enhance the strength of the glassy phase [1,4,8].

It is important to highlight that the presence of the glassy matrix in their structures enables this class of ceramics (ZLS) to be etched by hydrofluoric acid even with the presence of zirconium dioxide crystals. This allows the creation of micro-mechanical retentions on the cementing surface and resin bond improvement [9], different from the characteristics observed on the zirconia polycrystals based materials (non-etchable).

The occlusal thickness of ceramic restorations may affect the fracture resistance, since the strength of ceramic is inversely related to the square of ceramic thickness [10]. Chen et al. [11] have showed a linear relation between the ceramic thickness and the fracture resistance for a lithium disilicate-based glass ceramic, however they stated that between 0.5 and 1.5 mm thick the fracture resistance did not change much. Also, it is well known that better bonding can lead to higher fracture resistance, as reported by a previous study in which higher fracture resistance was found to ceramic crowns luted with resin cements compared to other luting agents [12]. In this sense, especially for thinner ceramic restorations, the adhesive protocol adopted might play a crucial role in the final strength of the assembly; aspects that currently have not been corroborated for ZLS ceramics yet.

Importantly, glass-ceramic materials might fail when subjected to dynamic and intermittent loading stresses owing to their brittle behavior [13]. Fatigue failure is considered as a fracture of the material due to progressive brittle cracking under repeated cyclic stresses at intensities below the material's normal strength [14]. Many in vitro studies have been developed involving the application of cyclic loads under moist environments to partly reproduce the clinical condition, as an attempt to infer the survival probability of ceramic restorations under different conditions [15–19]. In addition, Kelly et al. [20] developed an in vitro test assembly that better simulates the failure mechanism and stress state observed in clinically retrieved failed prostheses (e.g. radial cracks starting from the cementation surface — tensile side) [21].

Until now, data are scarce about the fatigue behavior of the existing ZLS glass-ceramics, specially concerning the effect of different thicknesses on the fatigue load-bearing ability of these materials. Therefore, this study aimed to evaluate and compare the influence of ceramic thickness on the fatigue failure load of two ZLS glass-ceramics adhesively cemented to a dentin analogue material. The tested hypotheses were that (1) the increase in ceramic thickness would increase the fatigue failure load of ZLS glass-ceramics; (2) the two ZLS glass-ceramics with different microstructures will present similar fatigue failure loads for similar restoration thicknesses.

2. Materials and methods

Information regarding the commercial name, manufacturers, composition, batch number and respective expiration date from all materials used in this study are described in Table 1.

2.1. *Specimen preparation*

CAD–CAM pre-fabricated ceramic blocks of Vita Suprinity (VITA Zahnfabrik H. Rauter GmbH & Co., Bad Säckingen, Germany) and Celtra Duo (Degudent GmbH, Hanau, Wolfgang, Germany) were shaped into cylinders ($\phi = 10$ mm) using a polishing machine (Ecomet 250 Grinder Polisher, Buehler; Lake Bluff, Illinois, USA). The cylinders were cut with a diamond blade under water-cooling (Isomet 1000, Buehler), resulting in 200 discs (n = 100 for each ZLS ceramic) of different thicknesses (n = 25) (Table 2). The occlusal surfaces of the discs were polished with 600- and 1200-grit silicon carbide (SiC) papers (3M, Sumaré, Brazil). Afterwards, they were cleaned with isopropyl alcohol in an ultrasonic bath (5 min), and crystallized in a furnace according to the manufacturer's instructions (Initial chamber temperature — 400 °C; time at the initial temperature — 8 min; temperature rate increase 55 °C/min; crystallization temperature for Vita Suprinity of 840 °C for 8 min and Celtra

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