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Effect of ceramic infrastructure on the failure behavior and stress distribution of fixed partial dentures

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ABSTRACT

Objectives. The effect of the ceramic infrastructure (IS) on the failure behavior and stress distribution of fixed partial dentures (FPDs) was evaluated.

Methods. Twenty FPDs with a connector cross-section of 16 mm^2 were produced for each IS and veneered with porcelain: (YZ) Vita In-Ceram YZ/Vita VM9 porcelain; (IZ) Vita In-Ceram Zirconia/Vita VM7 porcelain; (AL) Vita In-Ceram AL/Vita VM7 porcelain. Two experimental conditions were evaluated ($n = 10$). For control specimens, load was applied in the center of the pontic at 0.5 mm/min until failure, using a universal testing machine, in 37 °C deionized water. For mechanical cycling (MC) specimens, FPDs were subjected to MC (2 Hz, 140 N, 10^6 cycles) and subsequently tested as described for the control group. For YZ, an extra group of 10 FPDs were built with a connector cross-section of 9 mm^2 and tested until failure. Fractography and FEA were performed. Data were analyzed by ANOVA and Tukey's test ($\alpha = 0.05$).

Results. YZ16 showed the greatest fracture load mean value, followed by YZ16-MC. Specimens from groups YZ9, IZ16, IZ16-MC, AL16 and AL16-MC showed no significant difference for the fracture load.

Significance. The failure behavior and stress distribution of FPDs was influenced by the type of IS. AL and IZ FPDs showed similar fracture load values but different failure modes and stress distribution. YZ showed the best mechanical behavior and may be considered the material of choice to produce posterior FPDs as it was possible to obtain a good mechanical performance even with a smaller connector dimension (9 mm^2).

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1. Introduction

The introduction of CAD/CAM (computer-aided design/computer-aided machining) technology in dentistry and the development of ceramics with high crystalline content increased the range of application of all-ceramic restorations [1,2]. High-crystalline content ceramics, such as yttria stabilized tetragonal zirconia polycrystal (Y-TZP), alumina-based zirconia-reinforced glass-infiltrated ceramic (IZ) and polycrystalline alumina (AL), show higher fracture toughness values than those reported for glass-based materials [3], justifying their indication to produce all-ceramic fixed partial dentures (FPDs) [1,2].

On the other hand, as these ceramics show different chemical compositions and microstructure, different physical and mechanical properties are expected [3–5], which could influence the long-term clinical behavior of the restorations [2]. Clinical trials on zirconia-based all-ceramic FPDs reported infrastructure failure rates as low as 6%. In these studies, most clinical failures were related to chipping of the porcelain veneer and secondary caries, which are not infrastructural failures. Yet, the follow-up periods for these clinical studies are still relatively short, varying from 2 to 5 years [6–10]. One study successfully followed up three to five-unit Y-TZP FPDs for 10 years and reported a survival rate of 91.5% for the zirconia infrastructures [11]. For all-ceramic FPDs, the probability of failure is related to the properties of the ceramic systems, the size and shape of the connectors, the span of the pontic and to the position in the oral cavity [11–15]. FPDs most commonly fail from flaws located in the connector cervical area, where a higher stress concentration is produced during chewing [12,16,17].

Clinical studies provide reliable information on the longevity and failure behavior of dental restorations; however they are not easily carried out. On the other hand, laboratory tests and computer modeling represent more efficient research tools to obtain data on the stress distribution and failure behavior of dental prostheses [12,16]. Caution should be taken to guarantee that in vitro experiment properly simulates the clinical situation in all of its complexity [18]. The influence of the restoration configuration (multi-layer system) and its geometry in the stress distribution needs to be determined in order to better understand the long term behavior of all-ceramic prostheses. In vitro set-ups should take into account the processing steps used to produce dental restorations as to obtain the same flaw population leading to clinical failures [12,19]. Therefore, a more reliable prediction of the failure behavior of ceramic restorations could be obtained through in vitro evaluation of specimens that reproduce the shape of dental restorations, such as crowns and fixed partial dentures (FPDs).

In vitro tests should also simulate the loading and environmental conditions observed in the oral cavity [18]. Cyclic loading, as observed during chewing, contributes to the subcritical crack growth (SCG) of ceramic materials [20]. Ceramic lifetime may be overestimated when predictions are based only on static load and fracture toughness data, without considering the effect of cyclic loading [20–22]. When a ceramic material is subjected to a long period of intermittent stresses in a humid environment, below the critical stress level ($<K_{Ic}$) but above a threshold stress level ($\geq K_{I0}$), pre-existing flaws may grow slowly in areas of stress concentration or near the surface. When these pre-existing flaws reach a critical size due to continue loading, the mechanical capacity of the material is exceeded, resulting in catastrophic failure [23]. Under subcritical conditions, the initial flaw size distribution changes as a function of time, according to each material susceptibility to SCG. Thus, a different failure mode may occur for a prosthesis subjected to mechanical cycling in comparison to fast fracture [15].

The purpose of this study was to evaluate the effect of the ceramic infrastructure on the fracture load, failure mode and stress distribution of three-unit FPDs. This study tested the hypotheses that (1) the infrastructural material influences the failure behavior and stress distribution of FPDs and (2) the mechanical cycling effect on the fracture load of FPDs varies with the type of ceramic infrastructure.

2. Materials and methods

2.1. *Specimen fabrication*

FPDs were produced using three high crystalline-content infrastructure ceramics veneered with the recommended porcelain, as follows:

YZ – An yttria partially stabilized tetragonal zirconia polycrystal (Y-TZP) infrastructure (IS) (Vita In-Ceram YZ, Vita Zahnfabrik, Bad Sackingen, Germany) veneered with a porcelain (Vita VM9, Vita Zahnfabrik, Bad Sackingen, Germany);
IZ – A glass infiltrated zirconia-reinforced alumina-based ceramic IS (Vita In-Ceram Zirconia, Vita Zahnfabrik, Bad Sackingen, Germany) veneered with a porcelain (Vita VM7, Vita Zahnfabrik, Bad Sackingen, Germany);
AL – An alumina polycrystal IS (Vita In-Ceram AL, Vita Zahnfabrik, Bad Sackingen, Germany) veneered with a porcelain (Vita VM7, Vita Zahnfabrik, Bad Sackingen, Germany).

Stainless steel models simulating prepared abutment teeth were constructed with 4.5 mm height, 6° of taper and 120° chamfer as finish line [24]. The distance between the centers of the dies was 16 mm, corresponding to the distance between a lower second premolar and a lower second molar (span of 10 mm). An artificial gingiva was produced with acrylic resin (JET, Classico, Sao Paulo, SP, Brazil). Polyvinyl siloxane impressions of the model were taken (Aquasil^{TM}, Dentsply, Petropolis, RJ, Brazil) and a working cast was made using type IV special CAD/CAM stone (CAM-base, Dentona AG, Dortmund, Germany).

The stone cast was digitized by the internal laser scanner component of CEREC inLab unit (Sirona Dental Systems, Charlote, NC, USA) to generate a tridimensional image that was used to design the FPDs infrastructures from YZ, IZ and AL ceramic systems. After the milling process, YZ and AL infrastructures were sintered using the Zyrcomat furnace (Vita Zahnfabrik, Bad Sackingen, Germany), and IZ infrastructures were glass infiltrated (Z21N Zirconia Glass Powder, Vita Zahnfabrik, Germany) using the Inceramat 3 furnace (Vita