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Off-axis sliding contact reliability and failure modes of veneered alumina and zirconia[☆]

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ABSTRACT

Objective. All-ceramic dental crowns are popular because of their esthetics and biocompatibility. However, they often chip or fracture when subjected to repeated occlusal loading. Considerable efforts to improve the materials are being done through the study of fatigue and failure modes. The vast majority of fatigue studies have been conducted with uniaxial loading and no sliding action. We hypothesized different failure modes for porcelain veneered Y-TZP and that the reliability of porcelain veneered Y-TZP is higher than that of porcelain veneered alumina when subjected to fatigue under 30° off-axis sliding Y-TZP and alumina plates were porcelain veneered and cemented to aged composite blocks as a model for an all-ceramic crown on dentin.

Methods. Specimens ($n = 21$ per group) were fatigue at 30° off-axis with a hard sphere sliding contact in water, by means of a mouth-motion simulator apparatus.

Results. Although no difference between groups was found, the failure modes differed and there was a tendency to higher reliability for Y-TZP compared to alumina for a mission of 50,000 cycles at 150 N load.

Significance. Failure modes for alumina specimens were deep penetrating partial cone cracks and cementation internal surface radial cracks. Y-TZP specimens showed only surface damage with deep penetrating partial cone cracks extending to the veneer core interface, with no cementation surface radial cracking, which overall agrees with clinical finding. Angled sliding contact appears to better simulate oral function.

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1. Introduction

Apart from improved esthetics, ceramics promise superior biocompatibility and inertness. However, clinical experience

indicates that all-ceramic crowns are not as durable as their porcelain-fused-to metal counterparts, particularly on molar teeth [1]. While all-ceramic restorations composed of veneering porcelain and core structure provide excellent esthetics,

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their susceptibility to fracture due to the brittle nature of ceramic has been a subject of concern [2]. The failure rate for all-ceramic crowns, is quite high, and becomes a limiting factor in the lifetime performance, particularly with monolithic glass–ceramic systems [1,3]. Laboratory observations have demonstrated that even all-ceramic crown-like structures fabricated with esthetic but weak veneer porcelains on strong support alumina cores would appear to be subject to premature failure [4]. Yttria stabilized tetragonal zirconia polycrystal (Y-TZP) ceramic offers approximately twice the flexural strength and toughness, of alumina as a core material. Clinical studies in the longevity of veneered Y-TZP restorations have been recently reported that the Y-TZP core is very fracture resistant, but the fracture (large chips) of the porcelain veneer is the most frequent clinical shortcoming [5–7].

In attempts to simulate the failure of dental crowns it is more efficient to examine a simplified system. Dental crowns as multilayered structures have different stress distributions and load-bearing ability than monolithic types [8] therefore differences in mechanical behavior and fracture are expected. In addition to using simplified layer models to follow crack growth, reproducing the masticatory movements in a controllable manner is also crucial to investigate clinically related fracture behavior of ceramics [9].

The chewing cycle in posterior regions involves the combination of centric and eccentric excursions of mandibular buccal cusps relative to maxillary lingual cusps. The chewing motion is guided by cusp inclines of the posterior teeth of both arches with sliding contacts at various rates and magnitudes on the inclines. In this matter, the reproduction of sliding contact during chewing simulation in laboratory investigations becomes imperative to expose the tested sample to a more clinically realistic scenario. Kim et al. [10] compared failure modes and lifespan of off-axis sliding contact fatigue to uniaxial loading using a bi-layer model of soda-lime glass cemented to polycarbonate. The authors found that off-axis loading is more deleterious for contact-induced occlusal surface fracture, however it is less harmful for flexural radial fracture at the cement interface when compared to axial loading. The same authors [10] also showed a significant reduction on the lifespan due to cone fracture by over 2 orders of magnitude whenever off-axis sliding contact loading was performed. But there is still a need to understand the fracture behavior and clinical relevance when sliding contact fatigue testing is performed in four-layer structures using alumina and zirconia as core materials.

This study sought to investigate the reliability and failure modes of veneered alumina and zirconia four-layer models under 30° off-axis sliding contact step-stress fatigue. Two research hypotheses were described as follows:

- (1) Veneered alumina four-layer models are more susceptible to cement interface flexural radial cracking than veneered zirconia.
- (2) Higher reliability and higher loads for failure are expected for veneered zirconia four-layer structures when compared to veneered alumina in the same configuration.

2. Materials and methods

2.1. Materials systems

Ceramic flat layers were prepared from alumina blocks ($N=21$) (Procera All-Ceram, NobelBiocare, USA) and Y-TZP blocks ($N=21$) (Lava Frame, 3M/ESPE, St. Paul, MN, USA) 10 mm $\times$ 10 mm $\times$ 0.5 mm. The alumina and Y-TZP specimens were sintered according to the manufacturer's directions at a temperature of 1600 °C and 1550 °C respectively. The blocks of alumina and Y-TZP were mounted into a cutting machine (Isomet 1000, Buhler, Germany) and sliced to approximately 0.7 mm thickness with diamond wheel blade (11-4225, Buhler, Germany). The samples were then polished flat and parallel to approximately 0.5 mm using 280–600-grit diamond discs (Ecomet 4, Buhler, Germany).

A 1.5-mm layer of veneer porcelain was applied on the polished alumina and zirconia plates at a dental laboratory (Marotta Dental Studio, Inc.) following manufacturer recommendations. The veneer porcelain surfaces were then polished to a total thickness of 0.7 mm utilizing 600 grit diamond disc (Ecomet 4, Buhler, Germany). The final surface polishing of the porcelain was performed using 6–1 μ m diamond paste, followed by 0.5 μ m alumina paste on a cloth wheel under wet conditions (Ecomet 4, Buhler, Germany). The total thickness of the specimens was 1.2 mm (0.7 mm porcelain veneer and 0.5 core structure). The inner surface of each specimen was grit blast with 50- μ m aluminum oxide for 5 s, 0.5 MPa, at 5 mm distance. The specimens were then joined to hydrated composite substrates (the samples were aged in water for at least 30 days for full water sorption dimensional change) with final dimensions of 12 mm $\times$ 12 mm $\times$ 4 mm thick (Z100, 3M/ESPE) with a thin layer of resin cement (Rely X, ARC, 3M/ESPE). A 0.05-mm thick acetate spacer was used between the composite blocks and the specimen to obtain a cement thickness of approximately 50 μ m. All bonded specimens were incubated in water at 37 °C for 7 days prior to testing to allow cement hydration.

2.2. Single load to failure

Three specimens of each group were assigned for single load to failure (SLF) testing. A load (at 1 mm/min) was applied to the specimens ($n=3$ for each group) using a universal testing machine (Model 5566, Instron, Canton, MA, USA) equipped with a 1000-N load cell and 6.25 diameter carbide indenter. After testing, the mean load to failure for alumina and zirconia groups was calculated and these values used for establishing the upper load limits for fatigue testing. In this investigation step-stress accelerated mouth fatigue was employed [11].

2.3. Fatigue tests

The step-stress mouth-motion fatigue testing was performed, and recorded using an electrodynamic test system ELF 3300 fatigue-testing machine and Wintest software (Bose Corporation, EnduraTec Systems, Minnetonka, MN). A test jig held

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