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Influence of veneer and cyclic loading on failure behavior of lithium disilicate glass-ceramic molar crowns

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ABSTRACT

Objective. This *in vitro* study was designed to investigate the influence of the veneer and cyclic loading on the failure behavior of lithium disilicate glass-ceramic (LDG) crowns on maxillary first molar.

Methods. Sixty-four LDG crowns were divided into 4 groups ($n = 16$). Thirty-two monolithic crowns were fabricated from IPS e.max Press (M), and the remaining bilayered crowns using cut-back technique and conventional manual layering technique from IPS e.max Press/Ceram (B). Monolithic or bilayered crowns were subjected to single-load-to-fracture (SLF) testing using a universal testing machine, before (M1 and B1) and after exposure to sliding-contact fatigue (SCF) testing (M2 and B2), consisting of 1,200,000 mechanical cycles ($F_{max} = 98$ N). Data were statistically analyzed using two-by-two factorial design ANOVA. Fractographic analysis was performed to determine the fracture modes of the failed specimens.

Results. The mean fracture load values ($N \pm$ S.D.) for M1, B1, M2 and B2 were 2686 ± 628 N, 1443 ± 327 N, 2133 ± 578 N and 1464 ± 419 N, respectively. Significant differences were found between the failure loads of all groups ($P < 0.001$), except between groups B1 and B2. Bulk fracture initiating from the occlusal surface is the primary failure mode of monolithic and veneered LDG crowns. Cracking that initiated from core–veneer interfacial defects and ultimately resulted in bulk fracture is another major failure origin of veneered all-ceramic crowns.

Significance. Veneer application resulted in significantly lower fracture load values compared to monolithic LDG crowns. Cyclic loading is an accelerating factor contributing to fracture for monolithic LDG crowns but not for bilayered ones.

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1. Introduction

Lithium disilicate glass-ceramic (LDG) provides desirable mechanical properties, chemical resistance, biocompatibility, diminished plaque accumulation, accuracy of fit, esthetics, as well as wide indications including thin veneers, inlays, onlays, crowns, fixed dental prostheses in the anterior and premolar region and implant superstructures [1]. Due to the lower opacity and translucency of many core materials, bilayered ceramic crowns were introduced to obtain sufficient veneer support and to improve esthetics [2]. A long-term prospective study showed a survival rate of 97.4% for bilayered LDG crowns after 5 years and 94.8% after 8 years (93.8% for anterior crowns; 100% for posterior crowns) of clinical service [3]. The 5-year complication rate of 4.3% for bilayered LDG crowns exhibited a minor chipping rate of 2.1% and no bulk fracture, which are clearly lower than the mean values of 5-year chipping rate (3.0%) and fracture rate (2.5%) of all-ceramic crowns, respectively, irrespective of the materials used, as stated in a recent systematic review [4]. Based on clinical long-term data LDG bilayered single crowns can be considered as a reliable and promising treatment option that can be recommended in the anterior and posterior region [3].

However, when a core ceramic layer is veneered with porcelain, the resulting bilayered ceramic composite has a significantly lower strength and higher failure rate compared to the monolithic core ceramic [5–7]. The following four explanations have been suggested to rationalize these observations: (1) veneering porcelain was susceptible to failure at lower loads, because of lower fracture strength compared to core material [8]; (2) the use of veneering porcelains to improve esthetics often required a reduction of core thickness that could limit mechanical properties [9]; (3) the conventional manual layering technique involved laborious manual technique-sensitivity with the potential of defects within the veneer or at the core–veneer interface, that possibly affect the final quality of the restorations [10]; (4) the resultant multilayer structure increased the complexity of stress distribution within the restorations [11]. Residual stresses arise due to mismatch in coefficient of thermal expansion (CTE) between the porcelain and the underlying framework, and the possibility of thermal gradients and associated tempering stresses that develop during cooling [12].

When ceramic restorations are subjected to sufficient thermal and mechanical stresses over a period of time, the ceramic is prone to fatigue failure in the oral moist environment with saliva and cyclic masticatory forces are present [13]. Repeated tensile stresses, often coupled with the presence of defects at the core-cement interface, may result in subcritical crack growth eventually outweighing the material's fracture toughness and leading to a radial fracture. Studies have shown that these defects initiated cracking of the core material and are believed to be responsible for bulk fracture in bilayered samples as well as crowns [14–16]. However, controversies as to the above interpretation were raised recently [9,17,18]. It has been shown by comparing Weibull probability plots that fatigue (damage accumulation) is an acceleration factor for bilayered Y-TZP crowns, but not for PFM crowns [17]. For the failure of LDG crowns fatigue was not a strong acceleration factor [9]. However, veneered Y-TZP crowns were highly susceptible to fatigue induced veneer chipping, whereas monolithic LDG crowns were fatigue-resistant [18].

According to fatigue tests of standardized fully anatomical crowns, different failure modes for various all-ceramic systems were identified. The expected failure mode for monolithic LDG restorations is bulk fracture of the substructure and veneering porcelain [9]. So far, limited information is available on the effect of veneer application and cyclic loading on the failure behavior of bilayered LDG crowns. Furthermore, tests to examine how bilayered crowns behave compared to the monolithic ones should be carried out [19]. Analysis of fracture mechanics parameters combined with fractographic analysis is of great importance to understand fracture modes of bilayered LDG crowns. The null hypothesis of this study is that veneer application and cyclic loading will not affect failure behavior of LDG molar crowns. In the present study, the masticatory fatigue and subsequent fracture load of LDG molar crowns cemented to resin dies were evaluated. LDG (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein) and nano-fluorapatite veneering porcelain (IPS e.max Ceram, Ivoclar Vivadent, Schaan, Liechtenstein) were used to fabricate the crowns.

2. Materials and methods

2.1. Sample preparation

A standard complete crown preparation of a typodont maxillary first molar (A5A-500-#16, Nissin, Japan) was made and served as the master die with occlusal reduction of 2.0 mm, proximal axial wall reduction of 1.5 mm and 1.0 mm deep chamfer. Vinyl polysiloxane (3M ESPE, St. Paul, USA) impression of the finished master die was taken to fabricate sixty-four composite resin (Z100, 3M ESPE, St. Paul, USA) replicas. Before cementing the crowns, composite surfaces of the molar dies were roughened by sandblasting from a distance of approximately 5.0 mm, at 2 bar with 120 μm glass beads. All resin dies were stored in distilled water at 37 °C for 30 days to allow water hydration, which may eliminate the effect of water absorption dimensional expansion after cementation [20].

2.2. Fabrication of crowns

Sixty-four full-contour LDG crowns were fabricated according to manufacturer's instructions. Thirty-two monolithic fully anatomical crowns (IPS e.max Press, Ivoclar Vivadent) of 2.0 mm occlusal dimension without veneer were produced using the lost-wax technique. Thirty-two bilayered crowns were fabricated of 1.3 mm occlusal core thickness and 0.7 mm veneering layer confined to occlusal area. The cut-back technique was used for the core modification and the hand-layer technique for veneering (IPS e.max Ceram, Ivoclar Vivadent) [8]. Bilayered specimens were veneered using conventional sintering procedures according to the manufacturer's instruction (Table 1). The standard thickness control, the inner and outer surface treatment of the pressed crowns, and the cementation between crowns and resin replicas using adhesive resin (Panavia F, Kuraray Medical Inc., Japan) were also