DENTAL MATERIALS 29 (2013) 1132–1138

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/dema

Time-dependent fracture probability of bilayer, lithium-disilicate-based, glass–ceramic, molar crowns as a function of core/veneer thickness ratio and load orientation

Kenneth J. Anusavice[a,*], Osama M. Jadaan[b], Josephine F. Esquivel-Upshaw[a]

[a] University of Florida, Gainesville, FL, USA
[b] University of Mount Union, Alliance, OH, USA

ARTICLE INFO

Article history:
Received 27 February 2013
Received in revised form
22 May 2013
Accepted 12 August 2013

Keywords:
Core ceramic
Veneering ceramic
Lithium disilicate
Glass–ceramic
Load orientation
Crown design
Dynamic fatigue
Finite element analysis
Stress
CARES/Life
Fracture probability

ABSTRACT

Recent reports on bilayer ceramic crown prostheses suggest that fractures of the veneering ceramic represent the most common reason for prosthesis failure.

Objective. The aims of this study were to test the hypotheses that: (1) an increase in core ceramic/veneer ceramic thickness ratio for a crown thickness of 1.6 mm reduces the time-dependent fracture probability (P_f) of bilayer crowns with a lithium-disilicate-based glass–ceramic core, and (2) oblique loading, within the central fossa, increases P_f for 1.6-mm-thick crowns compared with vertical loading.

Materials and methods. Time-dependent fracture probabilities were calculated for 1.6-mm-thick, veneered lithium-disilicate-based glass–ceramic molar crowns as a function of core/veneer thickness ratio and load orientation in the central fossa area. Time-dependent fracture probability analyses were computed by CARES/Life software and finite element analysis, using dynamic fatigue strength data for monolithic discs of a lithium-disilicate glass–ceramic core (Empress 2), and ceramic veneer (Empress 2 Veneer Ceramic).

Results. Predicted fracture probabilities (P_f) for centrally loaded 1.6-mm-thick bilayer crowns over periods of 1, 5, and 10 years are 1.2%, 2.7%, and 3.5%, respectively, for a core/veneer thickness ratio of 1.0 (0.8 mm/0.8 mm), and 2.5%, 5.1%, and 7.0%, respectively, for a core/veneer thickness ratio of 0.33 (0.4 mm/1.2 mm).

Conclusion. CARES/Life results support the proposed crown design and load orientation hypotheses.

Significance. The application of dynamic fatigue data, finite element stress analysis, and CARES/Life analysis represent an optimal approach to optimize fixed dental prosthesis designs produced from dental ceramics and to predict time-dependent fracture probabilities of ceramic-based fixed dental prostheses that can minimize the risk for clinical failures.

* *Corresponding author at*: Department of Restorative Dental Sciences, College of Dentistry, University of Florida, Gainesville, FL 32610, USA. Tel.: +1 352 317 5553; fax: +1 352 846 1643.
E-mail addresses: kanusavice@dental.ufl.edu, kanusavice@gmail.com (K.J. Anusavice).

0109-5641/$ – see front matter
http://dx.doi.org/10.1016/j.dental.2013.08.206

1. Introduction

Core/veneer ceramic prostheses have been increasingly accepted recently as an alternative to metal–ceramic and full-metal prostheses for single-unit and multiple-unit restorations. These ceramic–ceramic prostheses have been used without sufficient evidence of clinical safety and effectiveness, especially regarding their susceptibility to fracture. Recent publications of clinical studies have reported chipping of veneered zirconia prostheses as “technical complications” [1]. However, none of these studies has reported the precise location or size of these fractures [2]. Thus, it is not feasible to assess the most likely cause of fractures in these cases or similar cases without additional biomechanics analyses.

Although several contributing factors, such as residual tensile stress from thermal contraction effects, framework design, veneer thickness, load orientation, grinding damage, aging effects of zirconia, inadequate elastic modulus of support structures, and parafunction have been proposed as causes of these structural failures, no single factor has been proven to be the dominant cause for the majority of these fractures.

The reported reasons for ceramic–ceramic restoration fractures include veneer chipping, core fracture, and greater load locations in the mouth, e.g., posterior tooth versus anterior tooth sites. Previous studies have shown that the probability of chipping fractures is significantly greater for ceramic–ceramic prostheses compared with metal–ceramic prostheses [1].

Based on CARES post-processing analyses [3], Fischer et al. [4] predicted that three-unit fixed dental prostheses made from monolithic E2C glass–ceramic and loaded at 100 N on the occlusal surface of the pontic are not likely to fracture over a period of 10 years or more ($p = 0.0026\%$).

Studart et al. [5] concluded from cyclic fatigue tests that all-ceramic bridges made from a lithium-disilicate-based glass–ceramic framework (Empress 2, Ivoclar Vivadent, Schaan, Liechtenstein) and an apatite-based veneer (Eris, Ivoclar Vivadent) were not recommended for use in the molar region. This recommendation is consistent with that of Marquardt et al. [6], who reported that the susceptibility of the fluorapatite-based veneering ceramic (Eris), the successor to Empress 2 Veneering Ceramic, was associated with the release of Ca^{2+}, $PO_4{}^{3+}$, and OH^- ions when subjected to tensile stress in water.

Based on a meta-analysis, Pjetursson et al. [7] reported a failure rate over 5 years of 6.7% for ceramic–ceramic crowns, which included reinforced glass–ceramic, which can be assumed to be Empress 2 glass–ceramic. However, the specific types of ceramic used for these prostheses were not identified. The most common type of failure was chipping fracture of the veneer ceramic, which occurred in 4.5% of the crowns. When used for posterior teeth, the 5-year survival rates of densely sintered alumina crowns (94.8%) and reinforced glass–ceramic crowns (93.7%) were similar to that (95.6%) for metal–ceramic crowns.

Since all of the reported clinical fractures have occurred over periods of months and years, stress corrosion and slow crack growth may be important variables to consider when analyzing or predicting the time-dependent fracture probability for bilayer ceramic and metal–ceramic prostheses. Thus, the objective of this study was to apply dynamic fatigue data, finite element analysis of three crown models, and CARES/Life analysis [3], to determine the effect of load orientation and thickness ratio of core ceramic to veneer ceramic on the predicted time-dependent fracture probability for posterior bilayer ceramic crowns that are made with a lithium-disilicate-based glass–ceramic core and its veneering ceramic.

Ceramic-veneered, lithium-disilicate-based core crowns were selected for the current study to characterize the risk for fracture of veneered core ceramics with three core/veneer thickness ratios and load orientations that simulate extreme bruxism and parafunctional behavior.

2. Materials and methods

2.1. *Ceramic specimen preparation*

The core ceramic, E2C (Empress 2 lithium-disilicate-based glass–ceramic, Ivoclar Vivadent, Schaan, Liechtenstein) and its veneering ceramic, E2V (Empress 2 Veneering Ceramic, Ivoclar Vivadent), were prepared separately as monolithic bars (Table 1) for four-point flexure testing in five groups of 30 bars each, with dimensions of 28 mm × 4 mm × 1.8 mm. The bars were fractured by dynamic fatigue tests at four stressing rates (0.05 MPa/s, 0.1 MPa/s, 1.0 MPa/s, and 10 MPa/s) in water. One 30-specimen inert strength group was tested at 10 MPa/s in silicone oil. Before testing, each bar was polished through 30 μm alumina abrasive and beveled slightly at a 45° angle along each longitudinal edge to minimize the risk for edge fracture. The load was applied by two steel rollers on the upper central area of each bar, which had a support length of 20 mm.

The flat bars were used to characterize the Weibull parameters for the E2C and E2V materials. The Weibull parameters reflect the characteristic strength, scale parameter, and statistical scatter in strength (Weibull modulus) for a given ceramic. It is standard practice in the ceramic structural reliability literature to obtain these parameters by fracturing simple specimen geometries such as tensile specimens, flexure bars, and C-ring specimens. The ASTM C 1161 test method describes the testing of flexure bars to generate the Weibull parameters for ceramic materials. These parameters were used in the present study to compute the reliability (time-dependent fracture probability) of the veneered glass–ceramic crowns.

2.2. *Finite element model*

Modeling of the bilayer ceramic crowns was performed using ANSYS Finite Element Analysis software (ANSYS, Inc., Canonsburg, PA). The molar crown models were designed with mesiodistal and buccolingual dimensions of 10 mm each, an occlusogingival height of 5 mm, and core/veneer thickness ratios of 0.33 (0.4 mm/1.2 mm), 0.6 (0.6 mm/1.0 mm) (Fig. 1), and 1.0 (0.8 mm/0.8 mm). A distributed load of 500 N was applied over an area of 2 mm^2 in the central fossa area of the crown models at angles to the horizontal axis of 35°, 70°, and 90°. The refined model was meshed and refined using ANSYS software. The half model of the crown (symmetric section)