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Three-dimensional characterization and distribution of fabrication defects in bilayered lithium disilicate glass-ceramic molar crowns

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ABSTRACT

Objective. To investigate and characterize the distribution of fabrication defects in bilayered lithium disilicate glass-ceramic (LDG) crowns using micro-CT and 3D reconstruction.
Methods. Ten standardized molar crowns (IPS e.max Press; Ivoclar Vivadent) were fabricated by heat-pressing on a core and subsequent manual veneering. All crowns were scanned by micro-CT and 3D reconstructed. Volume, position and sphericity of each defect was measured in every crown. Each crown was divided into four regions—central fossa (CF), occlusal fossa (OF), cusp (C) and axial wall (AW). Porosity and number density of each region were calculated. Statistical analyses were performed using Welch two sample *t*-test, Friedman one-way rank sum test and Nemenyi post-hoc test. The defect volume distribution type was determined based on Akaike information criterion (AIC).
Results. The core ceramic contained fewer defects ($p < 0.001$) than the veneer layer. The size of smaller defects, which were 95% of the total, obeyed a logarithmic normal distribution. Region CF showed higher porosity ($p < 0.001$) than the other regions. Defect number density of region CF was higher than region C ($p < 0.001$) and region AW ($p = 0.029$), but no difference was found between region CF and OF ($p > 0.05$). Four of ten specimens contained the largest pores in region CF, while for the remaining six specimens the largest pore was in region OF.
Significance. LDG core ceramic contained fewer defects than the veneer ceramic. LDG strength estimated from pore size was comparable to literature values. Large defects were more likely to appear at the core–veneer interface of occlusal fossa, while small defects also distributed in every region of the crowns but tended to aggregate in the central fossa region. Size distribution of small defects in veneer obeyed a logarithmic normal distribution.

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1. Introduction

Bilayered lithium disilicate glass-ceramic (LDG) fixed restorative materials have become popular because of their biocompatibility and esthetics. LDG core material, such as IPS e.max Press (Ivoclar Vivadent, Schaan, Liechtenstein) with high flexural strength of approximately 400 MPa and a fracture toughness of approximately 3.0 MPa m$^{1/2}$, in its bilayered application form has become a viable treatment of choice for fixed dental prostheses [1,2]. However, fracture of the framework material and chipping of the veneering porcelain from the underlying ceramic substrate have been reported for bilayered LDG restorations [3,4]. LDG crowns tend to have more chippings of the veneer resulting in a 5-year failure rate of 1.2%, while for metal-ceramic crowns, the incidence of veneer chipping was 0.4% after 5 years [5].

Several factors have been suggested to explain the failure in all-ceramic restorations: (i) defects [6], (ii) mechanical residual stresses [7], (iii) thermal residual stresses [8] and (iv) contact cracks [9]. However for all these factors, defects have been suggested to be the major cause of failure [10]. Under the combined effect of mechanical and thermal stresses, clinically observed failure was noted to initiate at the core–veneer interface or from surface defects, leading to chipping or fracture of restorations [11]. Defects such as pores, inclusion and small cracks may cause stress concentration and become the site of subcritical crack growth. As a consequence, ceramic materials may fracture at a stress far less than their original fracture strength under cyclic loading [12]. Thus, defects inside or on the surface of ceramic restoration are deemed to be critical for initiating clinical catastrophic fracture and chipping.

Defects are found to be present inevitably in most all-ceramic restorations originating during fabrication, regardless of fabrication technique or ceramic type [13]. However not all defects lead to failure of all-ceramic restorations. When a fracture initiating defect has a critical size, which is dependent upon the tensile stress prevailing, catastrophic crack propagation in ceramic materials is likely to occur [14]. Defect sizes of 30–40 μm equate very well with defects observed at the primary fracture origin of LDG materials [15]. Research results have shown that chipping mostly initiates from defects at the core–veneer interface [16]. Chipping and fracture are also observed to initiate from the defects in the marginal areas [17,18]. Since the clinical fabrication of glass ceramics may bring about both intrinsic and processing defects, the failure of LDG restorations has been suggested to be related to the size and location of such defects [19,20].

Clarifying the characteristics and distribution of defects in bi-layered LDG crowns should provide deep understanding of the relationship between defects and crown failure. In the literature, defect size measurement and calculation are generally based upon scanning electron microscopy 2D images and fractographic analyses. Defect distribution and associated shape complexity, however, are somewhat inhomogeneous. 2D analysis from polished cross-sections may underestimate the quantity and size of defects. In comparison, 3D analysis is deemed to be suitable to authentically acquire the entire data-set of the larger defects. Micro-CT provides the possibility for conducting nondestructive studies on 3D morphologies of dental material structures [21]. A recent study taking advantage of micro-CT analysis has shown that multiple pores ranging from ϕ50 to ϕ300 μm existed within the veneer and core of all-ceramic crowns [22].

The aim of the present study was to elucidate the relationship among the size, shape and distribution of fabrication defects in bi-layered LDG crowns by means of micro-CT, 3D reconstruction and statistical analysis. Bilayered molar crowns will be selected for investigating the characteristic form and distribution of fabrication defects of a more complicated anatomical morphological structure. The information is essential for ongoing mechanical property research [17,23]. The primary null hypothesis of this study is that the tested main parameters of the defects, either in core or in veneer, cannot be describe with any other known statistical model.

2. Materials and methods

2.1. *Specimen preparation*

A typodont maxillary first molar (A5A-500-#16; Nissin) was prepared as a unified die. All undercuts were eliminated by axial reduction of 1.5 mm. The palatal occlusal surface was reduced by 2.0 mm evenly, while the buccal occlusal surface was reduced by 1.5 mm with functional cusp bevels. The deepest point of the central fossa was 2.0 mm. All sharp angles were subsequently rounded to a 1.0 mm deep chamfer finish line and a 6° convergence angle between tooth axis and lateral wall was prepared. Another maxillary first molar model tooth (A5A-500-#16; Nissin) was chosen as a unified core die and prepared by occlusal reduction of 1.5 mm, while the axial wall was reduced by 0.7 mm, providing space for veneering. All sharp angles were rounded.

2.2. *Fabrication of crowns*

The anatomically corrected cores (n = 10) were fabricated using the lost wax casting technique generated from impressions of the core dies, after which the wax cores were invested (SpeedVest; Ivoclar Vivadent). Wax was removed by heating and the resultant void was filled with pressable materials (IPS e.max Press, LT A1; Ivoclar Vivadent). Following the heat pressing procedure, the crowns were divested and sandblasted with 120 μm glass beads at a pressure of 2 bar. The cores were veneered (IPS e.max Ceram; Ivoclar Vivadent) in multi-layering/firing steps by an experienced technician following the manufacturer's instruction. The veneering process was began by conducting a wash firing of Dentin material (IPS e.max Ceram,Dentin; Ivoclar Vivadent) on the core. Then the first layer was then applied onto the core and fired according to the manufacturer's instruction. Second layering was taken on the thoroughly dry crown after first layering in order to complete any missing areas. The crown was final polished after the second firing.

2.3. *Acquisition of the defect data-set*

Acquisition of the defect data-set of LDG was performed using a commercial micro-CT system (μCT50, SCANCO, Bassersdorf,