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Effect of zirconia surface treatment on zirconia/veneer interfacial toughness evaluated by fracture mechanics method

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ARTICLE INFO

Article history:
Received 17 February 2014
Received in revised form 31 March 2014
Accepted 5 April 2014

Keywords:
Bilayer
Airborne-particle abrasion
Liner
Interfacial toughness

ABSTRACT

Objectives: The aim of this study was to evaluate the effect of the airborne-particle abrasion and liner application on the interfacial toughness between veneering porcelain and zirconia core by means of a fracture mechanics test.
Methods: Beam-shaped zirconia specimens were sectioned and divided into 4 groups according to different surface treatments as follows: Group C (control): no treatment; Group L: application of liner; Group A: airborne-particle abrasion with Al_2O_3 (sandblasting); and Group AL: airborne-particle abrasion and application of liner. The zirconia surfaces before and after sandblasting were observed and analyzed by SEM and white light interferometer. Specimens of each pretreated group were veneered with 3 core/veneer thickness ratios of 2:3, 1:1, and 3:2, corresponding to 3 phase angles respectively. Fracture mechanics test was performed on each specimen, the energy release rate G and phase angle ψ were calculated to characterize interfacial toughness. The experimental data were analyzed statistically using three-way ANOVA and the Tukey's HSD test. The surfaces of fractured specimens were examined by SEM and EDX.
Results: At each phase angle, the interfaces with no treatment had higher mean G values than that of other groups. All the specimens showed mixed failure mode with residual veneer or liner on the zirconia surfaces.
Conclusions: The toughness of zirconia/veneer interface with no treatment is significantly higher than that of interfaces subjected to liner application and airborne-particle abrasion.
Clinical significance: Liner application and airborne-particle abrasion seem to reduce zirconia/veneer interfacial toughness. Therefore, the two surface treatment methods should be applied with caution.

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http://dx.doi.org/10.1016/j.jdent.2014.04.005
0300-5712/

1. Introduction

All-ceramic restorations have become suitable alternatives to metal restorations in recent decades because of their excellent biocompatible properties and high aesthetic performance, which is attributed to the veneering porcelain bonded on the ceramic substrate.[1,2] However, delamination and chipping of the veneer are two common failure modes of ceramic/veneer prosthesis and have a high incidence rate of 6%–25% over 2–5 years,[2–8] which is significantly higher than that of metal/veneer restorations.[5,9–11] Delamination failures in all-ceramic restorations either originate from the veneer and propagate to the interface or originate from the ceramic/veneer interface.[12–14] Voids and flaws inevitably exist at the interface, and crack may initiate from these voids and flaws due to stress concentration under a certain loading. In vitro studies have reported that ceramic/veneer interface has lower bond strength and fracture toughness compared with metal/veneer interface.[15–17] Therefore, sometimes delamination between ceramic and veneer is partly related to the poor bond strength and toughness of the interface. And zirconia/veneer interface is an important and weak link in the all-ceramic system.

In order to improve zirconia/veneer interfacial adhesion, zirconia surface was treated with different methods, such as airborne-particle abrasion,[18–24] liner application,[18–20,25,26] polishing,[18,27] grinding,[19] acid etching,[22] laser etching,[24] and silica coating.[18] The purpose of surface treatment is to clean the zirconia surface, to increase the surface roughness, or to promote high surface energy and better wettability, and thereby to improve interfacial adhesion.[24] Some dental zirconia manufacturers recommended airborne-particle abrasion and liner application as routine pre-treatment methods. The interfacial adhesion and the failure mode were significantly affected by airborne-particle abrasion or application of liner material. However, it is still a controversial issue whether the two methods should be carried out to enhance the adhesion between zirconia framework and veneer.[2]

Kim et al.[20] observed that airborne-particle abrasion with 110 μm Al_2O_3 under a pressure of 0.4 MPa could improve bond strength. This positive effect of sandblasting in increasing veneer to zirconia bond strength was also confirmed in the previous studies.[24,28] However, Fischer et. al[18] found that sandblasting was not a necessary surface pretreatment to enhance bond strength; as well, some studies considered it decreased bond strength because it might initiate surface defects that can become stress concentration sources.[19,21,27] The effect of liner has been studied by shear, tensile and other tests.[18–21,25,26] Conflicting viewpoints also exist as to whether the liner is useful for the bonding.

The test methods in these studies—most prevalently the shear test and tensile test—evaluated interfacial adhesion in terms of bond strength. Specimens after bond strength test often showed cohesive fracture patterns within the veneer layer, which meant that the results did not represent the true bond strength of the interface. Interfacial toughness is another important property that evaluates the adhesion of the interface, representing the resistance of a material to crack propagation. Recently, a fracture mechanics test was performed and the negative influence of liner on the interfacial toughness was indicated.[15] The fracture mechanics test proposed by Charalambides et al.[29] was proved to be an effective method of measuring interfacial toughness, which can produce relatively reliable data.[15,16,29–31] However, few studies have been conducted to evaluate the interfacial adhesion between veneer and zirconia with different surface treatments using this test configuration.

The purpose of the present paper was to evaluate the effect of airborne-particle abrasion on the zirconia/veneer interfacial toughness with the fracture mechanics method, and to compare the results with the previous liner applied and non-treated specimens. Fracture mechanics parameters (energy release rate G and phase angle ψ), which represented interfacial toughness, were calculated from experimental data by means of finite element analysis (FEA). The null hypothesis was that airborne-particle abrasion on zirconia would improve the zirconia/veneer interfacial toughness compared with no treatment and liner application.

2. Materials and methods

2.1. *Zirconia preparation*

Interfaces with four different treatments were compared: Group C, no treatment; Group L, application of liner; Group A, airborne-particle abrasion or sandblasting with Al_2O_3; and Group AL, airborne-particle abrasion and application of liner (Fig. 1). The fracture toughness tests on interfaces with no treatment (Group C) and application of liner (Group A) have been performed and described in a previous work.[21] Therefore, in the present study, the same tests were performed on Group A and Group AL, and the experimental results in the 4 situations were compared together.

40 zirconia beams were sectioned from Y-TZP zirconia pre-sintered blocks (Cercon Zirconia; Dentsply DeguDent GmbH, Hanau-Wolfgang, Germany) by a diamond saw. Then they were sintered according to the manufacturer's recommendations. Among the 40 beams, 10 beams were randomly chosen to conduct surface observation, 5 of which were in advance sandblasted on the bonding areas with 110 μm alumina particles under a pressure of 0.4 MPa for 10 s at a distance of 10 mm and a direction perpendicular to the surface. The remaining 30 beams were also sandblasted, and used for fracture mechanics test. All the specimens were cleaned in a sonic bath filled with ethanol for 5 min and gently air-dried.

2.2. *Surface quality evaluation*

The 5 non-sandblasted and 5 sandblasted zirconia specimens were sputtered with carbon layers on surfaces, and they were observed under a scanning electron microscope (SEM, QUANTA FEG 250; FEI; USA). Due to the carbon-sputtering, the 10 specimens were not used in the follow-up tests. The surface quality of the remaining 30 zirconia specimens were evaluated by a white light interferometer (Wyko NT9300, Veeco Inc., Plainview, NY, USA) before and after sandblasting respectively to obtain surface topography and surface roughness.