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Effects of cementation surface modifications on fracture resistance of zirconia

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ABSTRACT

Objectives. To examine the effects of glass infiltration (GI) and alumina coating (AC) on the indentation flexural load and four-point bending strength of monolithic zirconia.

Methods. Plate-shaped (12 mm × 12 mm × 1.0 mm or 1.5 or 2.0 mm) and bar-shaped (4 mm × 3 mm × 25 mm) monolithic zirconia specimens were fabricated. In addition to monolithic zirconia (group Z), zirconia monoliths were glass-infiltrated or alumina-coated on their tensile surfaces to form groups ZGI and ZAC, respectively. They were also glass-infiltrated on their upper surfaces, and glass-infiltrated or alumina-coated on their lower (tensile) surfaces to make groups ZGI2 and ZAC2, respectively. For comparison, porcelain-veneered zirconia (group PVZ) and monolithic lithium disilicate glass–ceramic (group LiDi) specimens were also fabricated. The plate-shaped specimens were cemented onto a restorative composite base for Hertzian indentation using a tungsten carbide spherical indenter with a radius of 3.2 mm. Critical loads for indentation flexural fracture at the zirconia cementation surface were measured. Strengths of bar-shaped specimens were evaluated in four-point bending.

Results. Glass infiltration on zirconia tensile surfaces increased indentation flexural loads by 32% in Hertzian contact and flexural strength by 24% in four-point bending. Alumina coating showed no significant effect on resistance to flexural damage of zirconia. Monolithic zirconia outperformed porcelain-veneered zirconia and monolithic lithium disilicate glass–ceramics in terms of both indentation flexural load and flexural strength.

Significance. While both alumina coating and glass infiltration can be used to effectively modify the cementation surface of zirconia, glass infiltration can further increase the flexural fracture resistance of zirconia.

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1. Introduction

Yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) has high strength of 800–1200 MPa and fracture toughness of 4–6 MPa m^{1/2} [1,2]. It serves as an excellent material for all-ceramic restorations. However, zirconia is opaque and does not match the natural color of human teeth [3]. Thus, zirconia restorations need to be veneered with esthetic porcelain to improve their esthetics. These bilayered structures often cause clinical complications in porcelain-veneered zirconia crowns and fixed partial dental prostheses (FDPs). This is because they are prone to chipping and delamination of the overlay porcelain [4–8] by 25% after 31 months [9] and 13% after 38 months [10] *in vivo*. To overcome chipping complications in veneered zirconia structures, monolithic zirconia structures with improved esthetics have been developed [11]. This was achieved by infiltrating glass into zirconia surfaces to provide shade options and better translucency [12].

Another limitation of zirconia crowns and FDPs is their insensitivity to the etching-silane bonding technique. To establish adequate zirconia-luting agent bonding strength, surface modifications of zirconia are required [13,14]. Traditionally, airborne particle abrasion is used to modify the zirconia surface for mechanical retention [1,15]. This process produces a protective layer of compressive stresses, which may impede fracture [15]. It also introduces microcracks, which may accelerate failure [16]. The formation of a compressively stressed layer in zirconia results from work hardening and volume expansion induced by a tetragonal–monoclinic phase transition [16–18]. The microcrack generation during airborne particle abrasion is attributed to the mechanical impact of abrading particles on zirconia surfaces. Thus, airborne particle abrasion can either reduce [19–21] or increase [22,23] the flexural strength of zirconia, depending on the type and size of abrading particles, the air pressure applied and the surface conditions of zirconia. Given the high-cycle fatigue nature of mastication, surface cracks in a zirconia restoration can eventually extend beyond the compressive surface layer, diminishing the fatigue strength of the restoration. Strength reduction is a major cause for failures in ceramic restorations, due to the development of tensile stress-induced radial cracks at the cementation surface [15,24–26].

To improve the luting cement bonding strength, alumina coating [27,28] and glass infiltration on zirconia cementation surfaces [12] have been used. The non-invasive nanostructured alumina coating on zirconia surfaces can survive the thermal cycling, significantly improving the resin-bond strength to zirconia ceramics [27]. The glass infiltration into zirconia surfaces has enabled the usage of the standard etching-silane technique to selectively remove the glass phase in the graded glass structure and create a three-dimensional surface morphology, increasing the resin bond strength [12]. However, effects of these surface modifications on the fracture resistance of zirconia are not known.

Accordingly, the present study aims to investigate effects of zirconia surface modifications on its fracture resistance using Hertzian indentation and four-point bending techniques. Our research hypotheses are (1) glass infiltration and alumina coating on the cementation surface of zirconia monolith

Table 1 – Test groups and their abbreviations.

Materials	Group abbreviations
Monolithic Y-TZP	Z
Monolithic Y-TZP with glass infiltration (GI) on the cementation surface	ZGI
Monolithic Y-TZP with glass infiltration on the cementation and occlusal surfaces	ZGI2
Monolithic Y-TZP with alumina coating (AC) on the cementation surface	ZAC
Monolithic Y-TZP with alumina coating on the cementation surface and glass infiltration on the occlusal surface	ZAC2
Y-TZP veneered with overlay porcelain ^a	PVZ
Monolithic lithium disilicate glass-ceramic ^b	LiDi

^a VM9, Vita Zahnfabrik, Bad Sackingen, Germany.
^b IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein.

significantly increase its load bearing capacity; and (2) the load-bearing capacity of monolithic zirconia is significantly greater than commercial porcelain-veneered zirconia and monolithic lithium disilicate glass–ceramic structures.

2. Materials and methods

2.1. Specimen preparation

2.1.1. Fabrication of ceramic specimens

Five experimental zirconia groups and commercial ceramic compositions were utilized in this study, which are summarized in Table 1.

Group Z were monolithic Y-TZP specimens. The material was made from 28 nm diameter powders of Y-TZP containing 5.18 wt% Y₂O₃ (TZ-3Y-E grade, Tosoh, Tokyo, Japan) for green compacts of 80 mm × 64 mm × 15 mm using cold isostatic press at 200 MPa. The green compacts were cut into blocks of 16 mm × 16 mm × 3 mm using a low-speed saw (Isomet Low Speed Saw, Buehler, Lake Bluff, Illinois, USA) with a diamond blade. After cutting, the green blocks were polished with 600-grit silicon carbide grinding paper (CarbiMet™ 2, Buehler, Lake Bluff, Illinois, USA) to remove machining grooves. The polished green blocks were then sintered at 1450 °C for 2 h in a box furnace (Lindberg/Blue M, Thermo Scientific Corp., Waltham, MA, USA) with a heating/cooling rate of 10 °C/min. During sintering at 1350–1450 °C, the Y-TZP material underwent a volumetric shrinkage of approximately 24%.

Group ZGI were the specimens of monolithic Y-TZP with glass infiltration (GI) on cementation surfaces. The polished Y-TZP green blocks were pre-sintered at 1350 °C for 1 h and cooled to room temperature at a heating/cooling rate of 10 °C/min to produce templates for glass infiltration. A uniform, powdered glass slurry was coated on cementation surfaces of the pre-sintered Y-TZP specimens and then dried in air. The glass consisted of 65.5 wt% SiO₂, 11.7 wt% Al₂O₃, 10.0 wt% K₂O, 7.3 wt% Na₂O, 3.0 wt% CaO and 2.5 wt% Tb₄O₇ [12]. Glass infiltration and densification of the coated specimens were carried out simultaneously by heat treatment at

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