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# Biaxial flexural strength of the bilayered disk composed of ceria-stabilized zirconia/alumina nanocomposite (Ce-TZP/A) and veneering porcelain

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A B S T R A C T

*Objective.* Herein we investigated the flexural strengths of bilayered ceria-stabilized zirconia/alumina nanocomposite (Ce-TZP/A) disks using different veneering porcelains.
*Methods.* Commercial (VITA VM9, Cercon Ceram Kiss, and IPS e.max Ceram) and experimental porcelains (Vintage ZR with coefficient of thermal expansions: CTEs of 8.45, 9.04, and 9.61 ppm/°C) with various layer thicknesses (1.0, 1.5, and 2.0 mm) were applied to Ce-TZP/A disks (0.8 mm thickness, $n = 180$). Biaxial flexural tests of the specimens with the porcelain layer in tension were evaluated based on the piston-on-three-ball method (ISO 6872: 2008). The calculated strengths were statistically analyzed using the two-parameter Weibull distribution with the maximum likelihood estimation.
*Results.* Although no significant differences were observed among the experimental porcelains, most specimens with the thinner layer of commercial porcelain showed higher Weibull characteristic strengths at the external surfaces than those with the thicker layer. Irrespective of the porcelain material, the thinner porcelain layer showed significantly higher strengths at the interface between the layers. Fracture origins were always observed at the bottom surface and continuously propagated into Ce-TZP/A substrates. The maximum tensile stress was located at the interface in specimens with the 1.0 mm porcelain layer, except for IPS e.max Ceram. Porcelain delamination was dominant in the case of the higher CTE value and thicker layer thickness of the porcelain.
*Significance.* The calculated biaxial flexural strengths and the stress distributions for bilayered Ce-TZP/A disks were dependent on the porcelain materials. Optimum behavior was observed for a combination of a small CTE mismatch between the materials and a low core-to-porcelain thickness ratio.



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## 1. Introduction

For dental fixed prostheses, modern patients are prone to select all-ceramic restorations instead of metal-ceramic restorations due to adequate mechanical properties, esthetic and biocompatibility reasons [1]. In particular, zirconia-based all-ceramic restorations have a wide range of applications from single crowns to long-span fixed partial dentures (FPDs) with their high mechanical strengths [2]. In clinical applications, outstanding development and emergence of a variety of dental computer-aided design/computer-aided manufacturing (CAD/CAM) technologies have made it possible to use two main types of zirconia ceramics; yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) and ceria-stabilized zirconia/alumina nanocomposite (Ce-TZP/A) [3].

Zirconia ceramics have been historically employed as a prosthetic framework material to be veneered with porcelain, but are being used for monolithic (full-contour) restorations recently [4]. The alternative Ce-TZP/A is a limited application such as a framework material due to the absence of light transmission [3]. However, Ce-TZP/A has other advantages over conventional Y-TZP: higher fracture toughness, lower framework thickness required, and better durability against lower temperature degradation (LTD) [5–7]. In bilayered ceramic systems, the superior mechanical strength of the framework itself and the good compatibility of the framework material and veneering ceramic are prerequisite for long-term clinical success [8–10].

According to recent systematic reviews, 5-year survival rates of zirconia-based restorations using Y-TZP frameworks were lower than those of metal-ceramic restorations [11–14]. Further, the main clinical failures of both single crowns and FPDs were chipping of the veneering porcelain and loss of retention. In contrast, to the knowledge of the authors, unfortunately, only a few clinical evidences of fixed prostheses using Ce-TZP frameworks are published in short-term clinical observations (up to 3 years) [15–17].

Porcelain chipping or fracture is a common problem not only for all-ceramic restorations but also for metal-ceramic restorations. Differences in the coefficient of thermal expansion (CTE) between the framework and veneering porcelain, and phase changes during cooling after porcelain firing lead to a thermal mismatch (incompatibility) cause transient or residual stresses within fixed prostheses [18,19]. Moreover, the intensity of thermal residual stresses, which depend on the magnitude of CTE differences, influences the reliability of clinical success [20,21]. Theoretically, the CTE value of the veneering porcelain is set to be the same as or slightly lower than that of zirconia ceramics [3]. Because porcelain is mainly bonded to zirconia ceramics with mechanical interlocking and compressive stress [22]. Thus, the CTE value of commercial porcelain products (8.8–10.0 ppm/°C, 25–500 °C) adjusted for that of zirconia ceramic (Y-TZP; approximately 10.5 ppm/°C) [22]. Furthermore, Ce-TZP/A, which has different chemical compositions and microstructures, shows the lower CTE value (10.3 ppm/°C) than conventional Y-TZP [7,18]. Consequently, it is unknown how the porcelain CTE value is recommended for the Ce-TZP/A framework in bilayered systems, even though Y-TZP showed such clinical results as mentioned above.

Mechanical properties such as strength are the first parameter to be identified the clinical potential and limitations of dental ceramics [23]. Generally, the biaxial flexural strength test is a suitable method for dental ceramics in laboratory tests; namely, the strength under biaxial flexure is more reliably measured than that under uniaxial flexure because fixed prostheses are exposed to biaxial stresses in the oral cavity [24–26]. However, the piston-on-three-ball method in ISO 6872:2008 was defined for the monolithic material so that it was unavailable to calculate the biaxial flexural strength for multilayered materials [24]. To this end, the recent closed-form solutions derived by Hsueh et al. and Hsueh and Kelly are used to evaluate the strength for bilayered disks [25–28].

The aim of this study was to test biaxial flexural strengths for a bilayered porcelain-Ce-TZP/A system using commercial porcelain products. However, the strengths may be influenced by not only CTE mismatch between the veneering porcelain and zirconia substrate but also the chemical composition of the porcelain. Thus, additionally, experimental porcelains which have almost the same chemical composition with different CTE values were investigated for Ce-TZP disks. The null hypothesis was that the biaxial flexural strength and fracture mode of the bilayered Ce-TZP/A disks with various porcelain layer thicknesses would not be changed by either within commercial products or within experimental porcelains.

## 2. Materials and methods

### 2.1. *Preparation of the bilayered porcelain-Ce-TZP/A specimens*

Ninety Ce-TZP/A disks (C-Pro Nano-Zirconia, Panasonic Healthcare Co., Ltd., Tokyo, Japan) with fine polished surfaces ($R_a$; 0.04 μm) and three different commercial porcelain products (VM9: VITA VM9, VITA Zahnfabrik, Bad Säckingen, Germany; CCK: Cercon Ceram Kiss, Degudent, Hanau-Wolfgang, Germany; EMC: IPS e.max Ceram, Ivoclar Vivadent, Schaan, Liechtenstein) were obtained from the manufacturers (Table 1). Each disk was verified the dimension (12 mm diameter × 0.8 mm thickness) using an electronic digital caliper, cleaned and air dried.

Each disk was layered with the veneering porcelain and fired in a dental furnace (Austromat 654 press-i-dent, Dekema Dental-Keramiköfen GmbH, Freilassing, Germany) according to the manufacturer's instructions (Table A.1). The layer thickness was set as 1.0, 1.5 and 2.0 mm ($n$ = 10 per group). The layering procedure comprised of four steps as follows: the application of an opaque liner, then the first and second dentin, followed by glazing. During dentin application, a special holder was used to realize the accurate porcelain layer thickness on the disk. After dentin firing, the thickness of the specimen was examined, and corrected if necessary. Finally, the dimension of each specimen was verified after glazing.

Subsequently, the same procedures were carried out on the disks using experimental porcelains (Vintage ZR, Shofu Inc., Kyoto, Japan) with three different CTE values (8.45, 9.04, and 9.61 ppm/°C) to prepare specimens with three porcelain layer thicknesses (Table 1, $n$ = 10 per group).

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