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Thickness dependence of light transmittance, translucency and opalescence of a ceria-stabilized zirconia/alumina nanocomposite for dental applications

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ABSTRACT

Objectives. This study was conducted to investigate thickness dependence of light transmittance, translucency and opalescence of a commercially available fully-sintered ceria-stabilized zirconia/alumina nanocomposite for dental all-ceramic restorations.

Methods. Three disk samples of 16 mm in diameter and thickness ranging from 0.2 to 0.6 mm with 0.1 mm increment each were cut from a fully-sintered rod-shaped Ce-TZP/alumina nanocomposite (NANOZR, Panasonic Healthcare, Japan) and polished flat by using diamond slurry. Spectral light transmittance data under the CIE standard illuminant D65 were recorded at 10 nm intervals from 360 to 740 nm using a computer-controlled spectrophotometer. Average transmittance, translucency and opalescence parameters were determined as a function of sample thickness. Optical properties of a fully-sintered yttria-stabilized tetragonal zirconia polycrystals (Cercon® base, DeguDent GmbH, Germany) were also investigated as a reference. Two-way ANOVA was performed to determine the significant differences in various optical parameters among types of ceramic and thicknesses at $\alpha = 0.05$.

Results. Results of the two-way ANOVA showed that the average transmittance, translucency and opalescence parameters of both ceramic materials were significantly influenced by the type of ceramic and thickness ($p < 0.001$). Light transmittance of the NANOZR was significantly lower than that of the Cercon® base. For both ceramic materials, average transmittance of light and translucency parameter decreased with sample thickness following exponential functions. The NANOZR showed substantially higher opalescence parameters exceeding 20 CIE units when the sample thickness was nearly 0.3 mm. The prominent characteristics of high opalescence and low transmittance of light in the NANOZR was considered to be caused by its specific very fine interpenetrated intragranular microstructure and by a large difference of refractive indices of Ce-TZP and alumina components.

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Significance. High opalescence and low transmittance of light of the ceria-stabilized zirconia/alumina nanocomposite (NANOZR) are attractive properties for use as a substructure in fabricating porcelain-veneering-type esthetic all-ceramic restorations.

1. Introduction

Recent developments of various types of high-strength ceramic materials have led to their increasing applications to dental prostheses such as inlays, crowns, and load-bearing frameworks of long-span bridges. Among them zirconia-based ceramics are well known to possess excellent mechanical properties due to its transformation toughening mechanisms [1]. Typically, Y-TZP (tetragonal zirconia polycrystals stabilized with 3 mol% yttria) is one of the major zirconia ceramics used in dentistry [1,2]. The Y-TZP has been reported to show a flexural strength in the 800–1000 MPa range and a fracture toughness in the 6–8 MPa $m^{1/2}$ range evaluated by the indentation-fracture method [1].

Nawa et al. [3,4] developed a high strength and high toughness CeO_2-stabilized tetragonal zirconia polycrystals (Ce-TZP)/alumina nanocomposite. This ceramic nanocomposite possesses a novel interpenetrated intragranular microstructure, in which small alumina and Ce-TZP particles are trapped within Ce-TZP and alumina grains, respectively [4]. For an optimum composition with 0.05 mol% TiO_2 doped 10Ce-TZP/30 vol% Al_2O_3 composite, both high strength (950 MPa) and high toughness (18.3 MPa $m^{1/2}$ for the indentation-fracture method) were achieved [3].

The development of this tough and strong Ce-TZP/alumina nanocomposite triggered the increased number of research articles, in which mechanical properties [5,6], low-temperature aging degradation [5,7,8], biocompatibility [5,9], and wear resistance [5,7] were examined. Results of these various investigations guaranteed the safe application of this Ce-TZP/Al_2O_3 nanocomposite to substructures of dental all-ceramic restorations and bearing materials in orthopedic total joint replacements. Since this material is the toughest ceramic currently available for fixed dental prostheses, the thickness of Ce-TZP/alumina nanocomposite frameworks can be reduced to 0.3 mm [10]. Moreover, manufacturers and clinical researchers recommend the thickness of zirconia core should be in the range 0.3–0.5 mm [11–14].

Regarding the optical properties of zirconia-based core materials, Baldissara et al. [15] evaluated the translucency of eight commercially available different ceramics using the direct transmission method and demonstrated a relatively higher translucency of Lava™ Frame (3 M ESPE, St. Paul, USA) and a least translucent character of Cercon® base (Degu-Dent GmbH, Hanau, Germany) made of Y-TZP although a small amount of light passed through this material. Recently, Kanchanavasita et al. [16] compared contrast ratio of six commercially available zirconia-based dental ceramics and reported a relatively higher translucency of inCoris TZI (Sirona Dental Systems GmbH, Bensheim, Germany) and an opaque character of Cercon® base. Wang et al. [17] investigated relationship between translucency and thickness of various dental glass ceramics and zirconia ceramics. They reported that all of the zirconia ceramics showed some degree of translucency and their translucency parameters decreased exponentially with thickness [17]. However, little information is available concerning optical properties of the Ce-TZP/alumina nanocomposite.

Since veneering enamel and dentin porcelains are translucent, optical properties such as light transmittance, translucency parameter and opalescence parameter of the substructure ceramics are considered to affect esthetic outcome of the final all-ceramic restoration. Translucency is defined as the property of a material by which a major portion of the transmitted light undergoes scattering [18]. If the majority of light passing through a ceramic is intensely scattered and diffusely reflected, the material will appear more opaque [18]. If only part of the light is scattered and most is diffusely transmitted, the material will appear more translucent [18]. Opalescence is the process by which a material appears yellowish-red in transmitted light and blue in the scattered light perpendicular to the transmitted light [18]. The phenomenon is named after the appearance of opal stone [18].

Knowledge of optical properties of the Ce-TZP/Al_2O_3 nanocomposite is important when this material is used as a substructure (framework) of dental all-ceramic restorations. The objectives of the present study were to investigate the effects of sample thickness on light transmittance, translucency and opalescence of a fully-sintered Ce-TZP/alumina nanocomposite material. Since typical thickness of the frameworks made of zirconia ceramics ranges 0.3–0.5 mm in clinical practice [11–14], samples with thickness ranging from 0.2 to 0.6 mm, covering the above-mentioned thickness range in clinical practice, were examined in the present study. To compare optical properties of the Ce-TZP/alumina nanocomposite with those of the conventional zirconia material, a Y-TZP ceramic was used as a reference. The null hypotheses tested were that the average transmittance of light, translucency and opalescence parameters would not be affected by the type of ceramic or thickness.

2. Materials and methods

2.1. *Sample preparation*

Three disks of 16 mm in diameter and thickness of 0.22 to 0.62 mm with 0.1 mm increment each were cut from a fully-sintered rod-shaped Ce-TZP/alumina nanocomposite (NANOZR, Panasonic Healthcare, Ehime, Japan), where full sintering was performed at 1450 °C for 2 h. Both circular faces