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Effect of the number of coloring liquid applications on the optical properties of monolithic zirconia

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ABSTRACT

Objective. This study was aimed to investigate the effect of the number of coloring liquid applications on the optical properties of monolithic zirconia.

Methods. Eighteen monolithic zirconia specimens (27.6 mm × 27.6 mm × 2.0 mm) were fabricated and divided into 6 groups ($n = 3$). Each group was designated by the number of A2-coloring liquid applications (Group I to Group V) and Group O as a control. Color and spectral distribution of the specimens were measured with a double-beam spectrophotometer. CIE L^*, a^* and b^* relative to the standard illuminants D65 were measured in reflectance and transmittance modes. Color difference (ΔE^*_{ab}), translucency parameter (TP) and opalescence parameter (OP) were calculated. All measurements were performed on five different areas of each specimen. All data were analyzed by ANOVA and multiple comparison Scheffé test, Pearson correlations and linear regression analysis ($\alpha = 0.05$).

Results. With the increase of the number of coloring liquid applications, CIE L^* ($R^2 = 0.878$) and OP values ($R^2 = 0.701$) were decreased, but CIE b^* ($R^2 = 0.938$) was increased. However, TP values were not significantly changed. The color differences among groups ranged from 1.3 to 15.7 ΔE^*_{ab} units. Strong correlation was found between OP and Δb^* ($R^2 = 0.982$, $P < .01$).

Significance. Within the limitations of this study, it can be concluded that the number of coloring liquid applications with a single shade affects the lightness, yellow chromaticity and opalescence of monolithic zirconia, although its translucency cannot be controlled by the coloring procedure.

1. Introduction

Zirconia has been introduced and widely used as an esthetic material in dentistry. Due to its opaque white color, it has been used as a framework material and has been veneered with feldspathic porcelain. One of the major shortcomings of zirconia-based restorations is a cohesive failure of the veneering porcelain [1–3]. Thereby, CAD/CAM-generated monolithic restoration systems which consist of a single material without

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any veneering, have been developed [4]. Nowadays the advantages of monolithic zirconia restorations with an increased mechanical stability make them possible to expand their clinical indications [5]. In a recent clinical report [6], elimination of veneered porcelain on posterior zirconia crowns and fixed dental prostheses was performed for a clinical trial and presented an acceptable esthetic result. This clinical trial included several technical procedures, such as the application of coloring liquids on the pre-sintered zirconia block, surface characterizations, glazing and polishing of zirconia restorations, in order to mimic natural tooth color.

Determination of the color of teeth and porcelain crowns can be described by the "double layer effect". This means that the resulting color appears from a diffuse reflectance of the inner dentin or opaque porcelain layer filtered by the scattering of outer translucent layer [7]. Therefore, interactions of the optical scattering and absorption coefficients, thickness of the outer translucent material, and reflectance of the background substructure, can influence the changes of overall color parameters [8]. In contrast, the creation of esthetic monolithic zirconia restorations could be challenging since they are full-contour mono-layered restorations.

Although monolithic zirconia restorations have been introduced in dentistry, there have been few studies reporting coloring effect on their optical properties at a clinically relevant thickness. Furthermore, there is no standardization of coloring in terms of color, translucency and opalescence parameters of the monolithic zirconia restorations.

The purpose of this study was to investigate the effect of the number of coloring liquid applications on the color, translucency and opalescence of monolithic zirconia. The null hypothesis to be tested was that there was no significant difference in the optical properties between monolithic zirconia ceramics with the different number of coloring liquid applications.

2. Materials and methods

Monolithic zirconia-based ceramic specimens were investigated in this study; BruxZir which is yttria-stabilized tetragonal zirconia polycrystal (Table 1). Eighteen square-shaped, pre-sintered zirconia block (34.0 mm × 34.0 mm × 2.7 mm) were fabricated using a cutting machine (618 slicer, Harig, Niles, IL, USA).

Tanaka ZirColor of A2 shade was used as a coloring liquid (Table 1). It is designed to be brushed on and dried quickly with no drying time between each application and, thus no preheating is necessary before sintering. The coloring liquid was applied according to the manufacturer's recommendations with a synthetic nylon fiber brush (No. 156, Hwahong, Hwasung-si, Kyunggi-Do, Korea). These specimens were divided into six groups ($n = 3$) according to the number of coloring liquid applications. The specimen with no application was used as a control.

- Group O (control group): no application
- Group I: one time of application
- Group II: two times of application
- Group III: three times of application
- Group IV: four times of application
- Group V: five times of application

All specimens were then fired in a zirconia sintering furnace (LHT 0217, Nabertherm GmbH, Bahnhofstr, Germany). The sintering cycle was controlled as followings: The temperature was raised to 950 °C for 1.5 h and maintained for 2 h, and then raised up to 1550 °C for 1.5 h and maintained for 3 h. After sintering process, the shrinkage of specimens was *circa* 20%. The mean size of sintered specimens was 27.6 mm × 27.6 mm, verified with a Vernier caliper (Mitutoyo, Tokyo, Japan).

The grinding procedure was performed on the opposite side of colored surface of each specimen to adjust the final thickness to 2.0 mm by the horizontal grinding machine (HRG-150, AM Technology, Kyunggi-Do, Korea). Final thickness was checked with a digital height gauge (Digimicro ME-50HA, Nikon Corp., Tokyo, Japan) with the accuracy of 1 μm on five different sites (center and each corner of specimen) of each specimen. The thickness of specimens ranged from 1.79 mm to 2.03 mm. Colored surface of the specimen was neither grinding nor polishing after completion of sintering. All specimens were ultrasonically cleaned in distilled water for 5 min before testing.

Color and spectral distribution were taken with a double-beam spectrophotometer (Cary 5000 UV–vis–NIR Spectrophotometer, Agilent Technologies Inc., Santa Clara, CA, USA) using an integrating sphere attachment. The specular reflectance component was excluded (SCE mode) by gloss trap inserted. Relative reflectance data was recorded in the visible range from 380 to 780 nm at 5 nm intervals. Measurements were recorded in Commission Internationale de l'Eclairage (CIE) 1976 $L^*a^*b^*$ color space (CIELAB) relative to the standard illuminant D65 and CIE 1964 10° supplementary standard observer in the reflectance mode over a white background (CIE $L^* = 99.9701$, $a^* = -0.0711$ and $b^* = 0.0499$) and a black background (CIE $L^* = 4.7487$, $a^* = -1.6749$ and $b^* = -1.5844$), and in the transmittance mode. The white standard was polytetrafluoroethylene (PTFE) plate (SRS-99-020, Spectralon® Reflectance Standards, Labsphere Inc., North Sutton, NH, USA) and the black background was a black tile (CM-A101B, Konica Minolta Optics Inc., Tokyo, Japan). The spectrophotometer for this study was equipped with an integrating sphere of 150 mm diameter made with sintered PTFE. The geometry for the reflection measurements was 8°:*de* (eight degree: diffuse geometry, specular component excluded). The aperture size was 19 mm in diameter for the reflectance measurement. For the transmittance measurement, opaque black polyvinyl chloride (PVC) plate supported measuring aperture to make the aperture size 10 mm × 15 mm, because the original aperture size of the instrument was 10 mm × 35 mm for the transmittance measurement. The specimens of 27.6 mm × 27.6 mm for this study provided adequate area for color measurement. The white PTFE standard was used for zero/base correction before reflectance color measurement.

Color coordinates, CIE L^*, a^* and b^*, were determined from the transmittance and reflectance data using a computer software (Cary WinUV Software, Agilent Technologies Inc., Santa Clara, CA, USA). Each value was measured on five different areas of each specimen including the center of specimen by moving it to each quadrant direction slightly. Since the beam