©Operative Dentistry, 2021, **46-1**, 54-62

Masking of High-Translucency Zirconia for Various Cores

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Clinical Relevance

Various core materials with different shades affect the final color of high-translucency monolithic zirconia restorations. The blue core shows the greatest color difference in final zirconia restorations followed by metal, A3 dentin-shade resin core, and white core.

SUMMARY

The purpose of this study was to evaluate the masking ability of high-translucency monolithic zirconia for various core materials. A computer-aided design–computer-aided manufacturing system was used to design a zirconia disc with a diameter of 10 mm and a thickness of 1.0 mm. Four groups of cores (n=15 each) were fabricated with blue-colored dual-cure resin, white-colored dual-cure resin, A3 dentin-shade composite resin, and titanium block with 10-mm diameter and 5-mm thickness. Dual-cure, self-adhesive resin cement discs with a thickness of 25.0 ± 0.02 μm were fabricated. The color was measured using a handheld spectrophotometer. Color measurements of all specimens were performed on a white background. To assess the masking ability of zirconia, the difference between the values measured with zirconia on a white background and the values measured with zirconia on each of the four types of core material as a background with the cement specimens interposed (zirconia + cement + core) was determined. To enhance the optical connection between the specimens, distilled water was applied between each layer during each measurement.

The results showed that the value of ΔE was highest for the blue core followed by metal, A3 dentin-shade resin core, and white-resin core. No significant differences were observed between the metal core and the A3 dentin-shade resin core or between the A3 dentin-shade resin core and the white core. The blue core had the significantly highest ΔE value based on Tukey's honest significant difference test.

Different core materials affect the final color of high-translucency monolithic zirconia restorations. Thus, our study showed that the final color of high-translucency monolithic

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https://doi.org/10.2341/19-238-L

zirconia restorations could be affected by the type of core material used.

INTRODUCTION

The use of all-ceramic restorations has considerably increased since the introduction of zirconia in dentistry. Ceramics have become a universally accepted material of choice for the restoration of anterior as well as posterior teeth, because of the adequate mechanical characteristics and outstanding esthetics.[1]

To reduce the risk of veneer fracture and to simplify the process of restoration, manufacturers have recently introduced monolithic zirconia restorations.[2] The use of monolithic zirconia restorations is increasing in restorative dentistry because of their biocompatibility, superior esthetics, simple clinical technique, and low cost relative to cast gold restorations.[3] Additional characteristics of monolithic zirconia restorations include natural toothlike appearance, low corrosion potential, and low thermal conductivity.[4-6]

Zirconia restorations do not require excessive tooth preparation such as in glass-based all-ceramic crowns[7] owing to their strong mechanical properties (flexural strength of 900 to 1500 MPa).[8] However, monolithic zirconia restorations have compromised esthetics because of lower translucency as compared with that of glass ceramic restorations.[9] This could be attributed to the increased size of crystalline particles, which induce greater light scattering and reduced translucency because of the decreased passage of light through the material.[10]

Dental manufacturers and laboratories have gradually overcome this weakness and have recently been marketing high-translucency monolithic zirconia restorative materials that have high esthetics and excellent strength properties.[9] Such monolithic zirconia materials are decent alternatives to conventional materials used in esthetic restorations and meet the requirements of both patients and dentists by providing higher translucency without sacrificing strength properties.[9]

Of the high-translucency monolithic zirconia products recently launched in the market, Lava Esthetic Fluorescent Full-Contour Zirconia is 5Y-PSZ (5 mol% yttria partially stabilized zirconia) and consists of cubic-phase zirconia in concentrations greater than 50%.[11] Lava Esthetic is aimed at not only improving the translucency but also reproducing the fluorescence of the tooth itself, and it has been reported to have higher fluorescence than Lava Plus. The maximum value of the fluorescence spectrum of Lava Esthetic is about 450 nm (blue), a value very close to the fluorescence spectrum of bovine dentin. Lava Esthetic shows dentin-like fluorescence even in darker shades, such as A3.5, whereas Lava Plus is noticeably fluorescent only in lighter shades such as A1.[12]

The importance of the core color increases as the translucency of zirconia increases. Zirconia is used not only for the restoration of prepared teeth but also for the prosthetic restoration of implants, wherein it may cover a titanium abutment, as well as for the restoration of blue-colored cores when blue-colored core materials are used for accurate distinction of the margins in a wide range of restorations. As discussed, zirconia should possess a certain ability of masking the core, and hence, information about the type and thickness of zirconia with optimal masking ability and translucency will be continuously required.

Basso and others[13] stated that monolithic glass ceramics can mask C4-shade cores but not metal cores, and they have a lower color-masking ability compared with that of glass-ceramic–layered zirconia. Moreover, it was reported that the ΔE value decreased as the thickness of the monolithic substructure increased from 0.7 to 2 mm.[13]

Kim and Kim[14] compared the optical properties of precolored monolithic zirconia ceramics, veneered zirconia, and lithium disilicate glass ceramics and found that the amount of color change was beyond the acceptability threshold. They concluded that precolored monolithic zirconia ceramics may cause color mismatch because of high L^* and low a^* and b^* values.[14]

Tabatabaian and others[15] stated that if the treatment option is monolithic zirconia restoration on an A4 shade core material or a prepared tooth (with dentin color), the thickness of the restorative material should be at least 0.9 mm to attain an acceptable final shade, considering the size of the core and/or the possible amount of tooth removal required.[15]

However, monolithic zirconia used in several studies was a low-translucency block with high opacity, unlike those used in recent times, with enhanced translucency. Hence, the results showed considerable limitations for its use in esthetic restorations. Furthermore, with the growing demands of zirconia for implant restorations, knowledge about the possible degree of masking of titanium abutments has become increasingly important to enhance the outcome of esthetic restorations.

Therefore, the purpose of this study was to evaluate the masking ability of high-translucency monolithic zirconia for various core materials.

The null hypothesis was that different core materials would not affect the final color of high-translucency monolithic zirconia restorations.

METHODS AND MATERIALS

Zirconia Specimen Preparation

A computer-aided design–computer-aided manufacturing system (Rhinoceros 5 CAD program, Rhinoceros 5 SR 13, Robert McNeel & Associates, Seattle, WA, USA) was used to design a zirconia disc (Lava Esthetic Fluorescent Full-Contour Zirconia Discs [LE], 3M ESPE, St Paul, MN, USA) with a diameter of 10 mm and thickness of 1.0 mm. Shade A2 zirconia blocks were milled using the Roland milling machine (Roland DWX-52D, Roland DGA Corporation, Irvine, CA, USA), which was calibrated by the CAM software (hyperDENT, Open Mind Technologies AG, Wessling, Germany). After the completion of the milling process, specimens were sectioned from the sprue and were trimmed. Specimens were contained in a sintering box and were sintered according to the manufacturer's recommendations. Since they were manufactured in the A2 shade, the dipping process was not performed. The specimens were sintered at a maximum temperature of 1520°C for 12 hours in a sintering furnace.

Zirconia discs were sequentially polished with 600-, 800-, 1000-, and 1200-grit silicon carbide abrasive papers in a polishing machine accompanied by water cooling to obtain the predetermined thickness (1.0±0.02 mm). A digital micrometer (293 MDC-MX Lite, Mitutoyo Corp, Tokyo, Japan) with an accuracy of 0.002 mm was used to measure the thickness. Only one surface of the disc was polished to simulate clinical conditions.

Core Disk Preparation

Four groups of cores (n=15, each) were fabricated with blue-colored dual-cure resin (Core-flo DC, Bisco Inc, Schaumburg, IL, USA), white-colored dual-cure resin (Core-flo DC, Bisco Inc), A3 dentin-shade composite resin (Filtek Z350 A3 dentin, 3M ESPE), and titanium block (Osstem TS premilled abutment, Osstem Implant, Seoul, Korea). Acrylic plates were prepared with a hollow space of 10-mm diameter and 5-mm height to fabricate a mold for the resin core. The blue-colored and white-colored resin were added to the mold with the help of a Mylar strip (SKY Striproll 10, Suki Dental Co, Goyang, Gyeonggi-do, South Korea). When the mold was filled up to 5 mm, the Mylar strip was placed on the top of the resin. The core material was polymerized with a light-polymerizing unit (SmartLite Pen Style LED curing light, Dentsply DeTrey, Konstanz, Germany) for 40 seconds with an intensity of 800 mW/cm^2. An A3 dentin-shade composite resin was added in increments of 2 mm and light-cured with the curing unit as described previously. The resin cores were sequentially polished with 600-, 800-, 1000-, and 1200-grit silicon carbide abrasive papers in a polishing machine. The titanium core was custom fabricated using a titanium abutment block (Osstem TS premilled abutment) with 10-mm diameter and 5-mm thickness. The same micrometer was used to measure the thickness of the titanium core (5.0±0.02 mm). If the thickness was less than the intended thickness, the core was discarded.

Cement Disk Preparation

Dual-cure, self-adhesive resin cement (3M RelyX U200 A2, 3M ESPE) was used (Table 1). Cement was mixed according to the manufacturer's recommendations. The mixture of resin cement was applied between two polyester strips, and the strips were kept below a hard transparent plate under pressure of 9.8 N.[16] The cement was polymerized with a polymerizing light unit (SmartLite Pen Style LED curing light, Dentsply DeTrey) at an intensity of 800 mW/cm^2 for 20 seconds from each side.

The cured cement was trimmed with a blade to conform to the shape of the resin core disc. The thickness of the cement disc was adjusted with polishing. Until the intended thickness was obtained (25.0±0.02 μm), the cement specimen was polished and subsequently measured by digital micrometer.

Color Measurement

The color was measured using a handheld spectrophotometer (Vita EasyShade V, Vita Zahnfabrik, Bad Säckingen, Germany). A silicon putty index (3M ESPE Express STD, 3M ESPE) was fabricated to maintain similar conditions in all the specimens despite different materials being used and to avoid external light.[17,18] Color measurements of all the specimens were performed on a white background. To assess the masking ability of zirconia, the difference between the values measured with zirconia on the white background and the values measured with zirconia on each of the four types of

Table 1: *Materials Used in This Study*

	Material	Manufacturer	Lot No	Diameter, mm	Thickness, mm
Zirconia					
LE 1.0	Lava Esthetic Fluorescent Full-Contour Zirconia	3M ESPE, St Paul, MN, USA	3994896	10	1
Core					
Blue	Core-Flo DC Blue	Bisco Inc, Schaumburg, IL, USA	1800002442	10	5
Metal	Osstem TS premilled abutment	Osstem, Seoul, Korea	PTA18F234		
White	Core-Flo DC Opaque white	Bisco Inc, Schaumburg, IL, USA	170003296		
A3 shade resin	Filtek Z350	3M ESPE, St Paul, MN, USA	N718626		
Cement					
U200A2	RelyX U200 Automix self-adhesive resin cement	3M Deutschland GmbH	3722465	10	0.025

core material as a background with the cement specimens interposed (zirconia + cement + core) was determined. To enhance the optical connection between the specimens, distilled water was applied between each layer during each measurement.

The data were presented in L*, a*, and b* values according to the Commission International de l'Eclairage or International Commission on Illumination.[19]

ΔE values were calculated using the following formula:

$$\Delta E^*_{ab} = [(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2]^{1/2}$$

Vichi and others[20] provided three different ranges to differentiate between color shifts. A ΔE value less than 1.0 is considered undetectable by the human eye, and a ΔE value between 1.0 and 3.3 is considered visible by skilled operators but clinically acceptable. A ΔE value greater than 3.3 is not clinically acceptable, because it is appreciable by a nonskilled person.

Accordingly, in the present study, the clinically acceptable limit was set at a ΔE value of 3.3, the threshold used in several studies.

Statistical Analysis

Statistical analyses were performed using R statistical software, version 3.5.1 (R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria).

Significant differences between the groups were determined using the Tukey's honest significant difference (HSD) test and one-way analysis of variance (α=0.05).

RESULTS

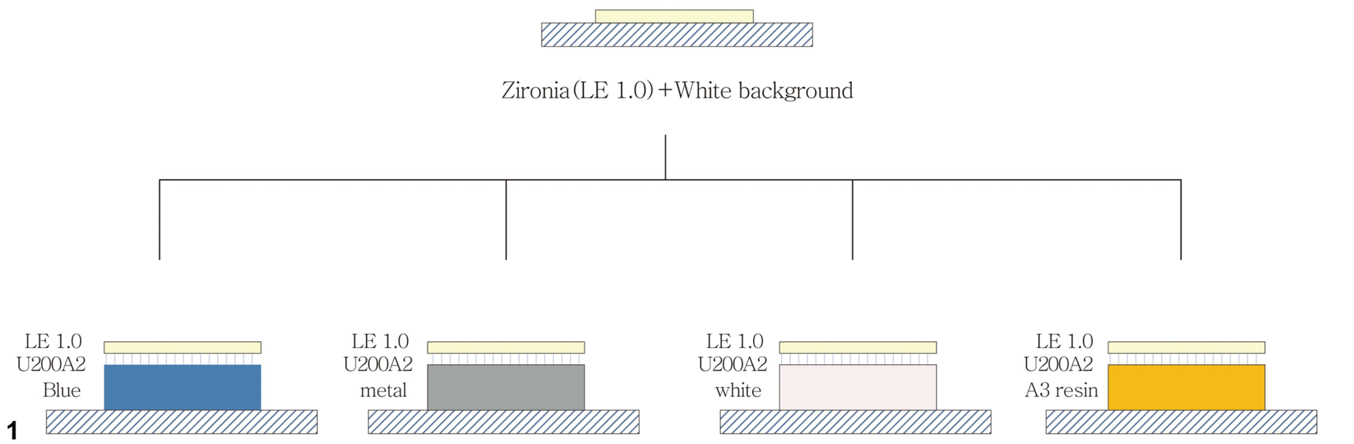
The experimental study protocol is summarized in Figure 1. The ΔE values of color change were computed by using the above-mentioned formula with the L*, a*, and b* values for LE 1.0 alone and the corresponding values for LE 1.0 combined with each of the four types of cores. All measurements were performed with a white background. Figure 2 shows the L*, a*, and b* values with zirconia on the white background and zirconia combined with cement and the four different core materials.

The results showed that the value of ΔE was highest for blue core, followed by metal, A3 dentin-shade resin core, and white-resin core (Table 2). No significant differences were observed between the metal core and the A3 dentin-shade resin core or between the A3 dentin-shade resin core and the white core. The blue core had the significantly highest ΔE value based on Tukey's HSD test.

DISCUSSION

According to the results, the highest change in color was evident with LE 1.0 mm combined with RelyX U200 A2 cement and the blue core. In contrast, no significant differences were observed in color between the metal core and A3 dentin-shade resin core, which is considered to have a similar color to a prepared tooth.

The zirconia and the cement used in this study were of the A2 shade; however, the shade of the core material was darker or lighter than A2, which made it impossible to mask the color of the core with zirconia and cement. Particularly, the zirconia used in this study showed high translucency, and hence, its masking ability was not optimum. However, with the increasing esthetic demands, efforts



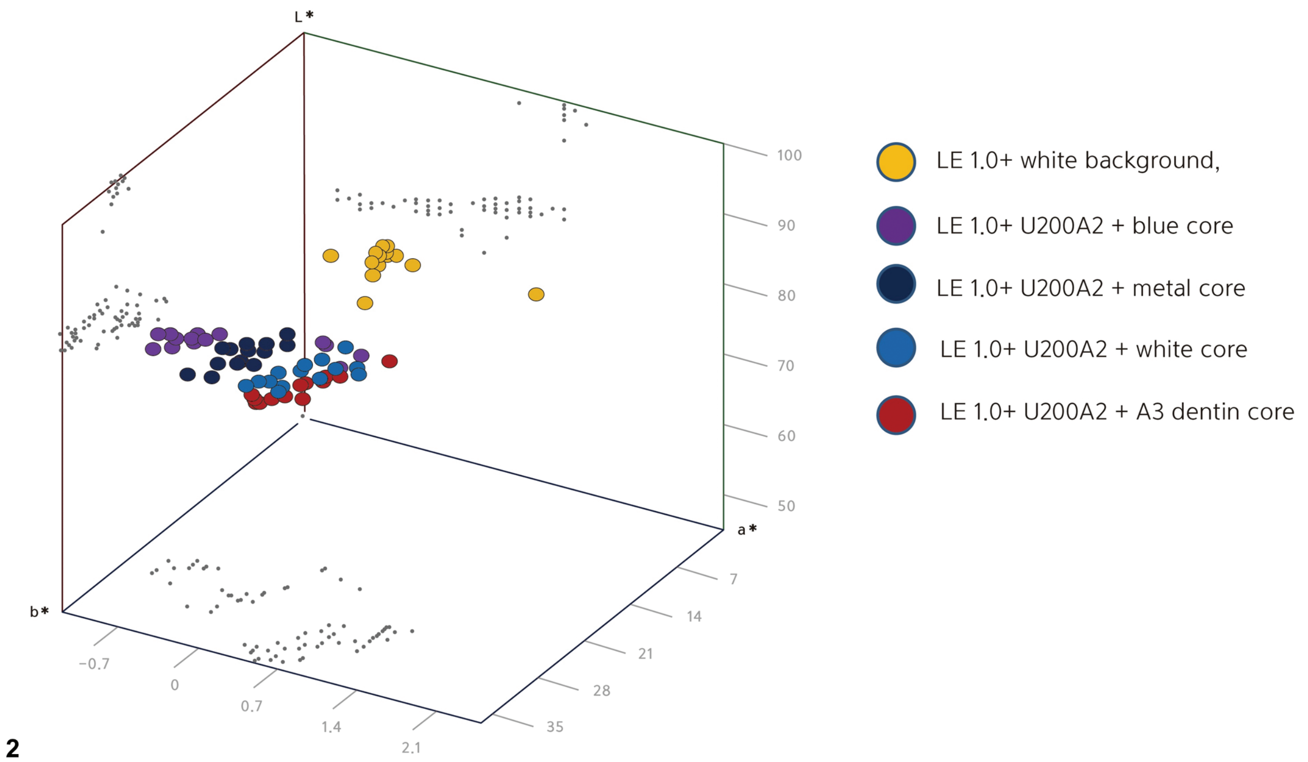


Figure 1. *Flowchart of the study. Color measurements were performed with zirconia (Lava Esthetic 1.0) laid on white background and zirconia combined with cement (U200A2) and four different core materials.*

Figure 2. *Three-dimensional plot of color distributions, which represent the L*, a*, and b* values of zirconia (Lava Esthetic [LE]) on white background and zirconia combined with cement (U200A2) and four different core materials. Yellow, LE 1.0 on white background; purple, LE 1.0 + U200A2 + blue core; navy blue, LE 1.0 + U200A2 + metal core; blue, LE 1.0 + U200A2 + white core; red, LE 1.0 + U200A2 + A3 dentin core.*

should be directed to determine the optimal methods for using monolithic zirconia with improved translucency.

According to our results, color change in the final restoration was not significant between the metal (titanium) core and A3 dentin-shade resin core. This suggests that there is no significant difference in the final color when titanium, the material commonly used for implant abutments, or A3 dentin-shade resin, which is the shade of a prepared tooth, are restored with zirconia.

The translucency of zirconia has been studied extensively in the literature. According to Church and others,[9] even the most translucent zirconium

Table 2: *Measurements of Color Difference*[a]

Core	Blue (n=15)	Metal (n=15)	A3 Dentin (n=15)	White (n=15)
ΔE	21.5 ± 2.0 A	19.0 ± 1.6 B	17.3 ± 2.1 BC	15.8 ± 2.0 C

[a] Differences were measured between LE 1.0 on a white background and LE 1.0 combined with each of the four core materials and resin cement. All specimens were measured against a white background. The different uppercase letters indicate differences between the core materials (in the rows; $p<0.05$).

oxide material is not as translucent as lithium disilicate, but high-translucency zirconia material at a clinically acceptable minimal thickness is as translucent as lithium disilicate. Moreover, flexural modulus and flexural strength are significantly greater in high-translucency zirconia materials compared with that in lithium disilicate. Considering this, the level of translucency comparable with that of lithium disilicate can be achieved by the use of zirconia with minimum removal of tooth structure. Therefore, in the present study, it was determined to study the translucency of zirconia while maintaining the thickness of zirconia specimens within a range of statistical insignificance.

The increased translucency of LE, in particular, is assumed to be achieved by controlling the proportions of the crystalline phases. Translucency increases if the amount of the cubic phase increases and that of the tetragonal phase decreases, because the cubic phase prevents the scattering of light from the grain boundary.[21] The amount of the cubic phase increases as the level of yttria increases, consequently improving translucency.[22]

Increased translucency in zirconia is achieved from the structural change that occurs when increasing the yttria content from 3 to 5 mol%. The tetragonal zirconia phase reduces the concentration of cubic phase particles, resulting in decreased flexural strength (600-800 MPa).[23] Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is zirconia stabilized with 5.18 wt% yttria and a tetragonal phase in a concentration of 90% or more; however, the yttria concentration should increase to 7 wt% or higher to achieve adequate translucency.[24] It has been reported that the combination of a mean grain size less than 80 nm and a 75% tetragonal–25% cubic phase proportion, with a porosity content less than 0.01%, can produce a translucent zirconia ceramic.[24] Moreover, translucency can be increased to an ultra-level, if the cubic phase is increased to 50%. Reduction in grain size and increase in the cubic phase may, however, decrease the flexural strength and fracture toughness of zirconia.[25] Translucency decreases as reflection increases. According to Zhang,[24] internal light scattering is influenced by porosity, additives, defects, grain size and their boundary, crystalline phase, and thickness. High porosity increases light scattering and reduces translucency, as the refractive index between air (n=1) and zirconia (n=2.1-2.2) is different.[26] Porosity can be controlled by increasing a sintering parameter such as temperature, cycle, and/or time.[27]

In the study conducted by Yu and others,[28] the translucency parameter (TP) represented the color difference between a material over a black and a white background. The TP of human dentin was found to be 16.4 and that of enamel to be 18.1 at a thickness of 1.0 mm, similar to the TP of glass ceramic (14.9-19.6). According to Wang and others,[29] the TP of monolithic zirconia was 5.5 to 13.5 at a thickness of 1.0 mm; in particular, the TP of Lava Plus high-translucency zirconia was 13.5, which is lower than that of human dentin. Sulaiman and others[10] reported that TP values of 1.0 mm zirconia in the specimen group were 11.16 to 15.3, lower than the TP values of enamel and dentin. They concluded that several improvements would be required for zirconia to match the translucency of natural teeth optimally. However, in the present study, the TP values of zirconia of thickness 1.0 mm were higher, with 14.91 for Lava Plus and 17.36 for LE. Thus, the TP of LE was higher compared with that of human dentin of the same thickness but lower compared with that of human enamel. Changes in the crystalline structure of zirconia are believed to have contributed to the improved translucency.

Tabatabaian and others[17] investigated the thickness of zirconia coping required to mask the color of a variety of restorative materials and reported that the optimum thickness for achieving an ideal masking ability was 0.4 mm for A1 and A3.5 shade composite resin, A3 shade zirconia, and nonprecious gold alloy, whereas it was 0.6 mm for amalgam and 0.8 mm for nickel-chromium alloy.[17] In clinical situations with existing cores, various options are available to compensate for the effect of the background, such as using an opaque cement, increasing the thickness of veneering porcelain, or fabricating a zirconia coping with a proper thickness.[17]

The best possible luting agent should be used to achieve high bond strength after cementation. Resin cement is often preferred for the cementation of all-ceramic restorations because of its low solubility, good esthetics, and high bond strength.[30] Moreover, it is used to modify the final color of the restoration and mask the color of the substructure.[31] The self-cure resin cement does not require curing by the use of visible light and hence has an advantage in deep cavities or if a thick restorative material is used. However, manipulation of self-curing resin cement has a risk of entrapment of air bubbles and resultant formation of voids on the adhesive interface. In addition, the color of the resin cement can have a slightly yellowish tinge if a tertiary amine catalyst is used. A major advantage of light-cure resin cement is the ease of use. It does not have a limitation of working time, and excessive luting material can be easily removed prior to curing. However, the amount of light reaching the floor of the cavity is decreased in deep cavities in the case of a ceramic- or resin-based composite restoration, thus negatively affecting light activation of the resin cement. Dual-cure resin luting agents have been developed in an attempt to combine the ideal properties of self-cure and light-cure resin cements. The chemical curing components guarantee complete polymerization in the floor of deep cavities, while photo-activation ensures immediate finishing after exposure to curing light.[32]

Rosenstiel and others[33] reported that the film thickness of the luting agent can directly affect long-term clinical success. According to the guidelines by the American Dental Association (ADA), a maximum film thickness of 25 μm is allowed for a type I cement, which is designed for the accurate seating of precision attachments and for other uses. ADA type II materials, which are recommended for uses except the cementation of precision attachments, can have a maximal film thickness of 40 μm.[34] Leinfelder and others[35] suggested that the interfacial gap should not exceed 100 μm, particularly on the occlusal surface, since wider gaps commonly result in extensive wear of the composite resin luting agent. Therefore, in this study, the resin cement thickness was determined as for type I cement (25 μm).

There are a few limitations of this study. First, variables associated with aging-induced color changes were not considered. With aging, zirconia may show a change in translucency, which could be attributed to tetragonal-to-monoclinic phase transformation. Incremental change in the microstructure of Y-TZP with aging could be related to a change in light reflection of the monoclinic and tetragonal crystals. Furthermore, surface porosities in the region of phase transformation can change (microcracks) because of a change in the volume of the monoclinic crystal, influencing translucency.[36] Further, colors of the cement and resin core are expected to change with aging. Specifically, it is expected that the color of resin-based materials may shift toward yellow because of water absorption by components such as triethyleneglycol dimethacrylate and 2,2-bis (4-[2-hydroxy-3-methacryloyloxy] phenyl) propane and that the color may change as a result of the concentration of uncured camphorquinone depending on the polymerization rate.

Second, the specimens were not directly cemented in this experiment. With direct cementation, light reflection and refractive index would have been different, exerting differing influences on translucency and color changes and producing differing outcomes than the current laboratory experiment.

Third, the cement thickness used in the experiment was relatively less. The typical resin cement thickness of 100 μm has been used in several previous studies, which is thicker than the thickness used in the present experiment. The effect on color change may have been smaller in this study because the resin cement discs were thinner. The thickness used in the current experiment, 25 μm, is the thickness required for more precise restorations such as inlays and onlays. Accordingly, it is speculated that if the cement is thicker, the masking effect may be stronger, and the masking ability of different cement types may differ.

Lastly, the thickness of zirconia considered in this experiment was 1.0 mm, which is greater than the minimal thickness (0.8 mm) recommended for LE by the manufacturer. If we had used different thicknesses of zirconia, we might have obtained different results. Therefore, comparisons of a larger range of thicknesses, up to 2.0 mm, would have produced more clinically useful findings.

CONCLUSION

Different core materials would affect the final color of high-translucency monolithic zirconia restorations. The blue core showed the greatest color difference in final zirconia restorations followed by metal, A3 dentin-shade resin core, and white core. Metal core and A3 dentin-shade resin core did not show a significant color difference in the final zirconia restoration.

Acknowledgement

This work was supported by the National Research Foundation of Korea grant funded by the Korea government (NRF-2018R1A1A1A05018328).

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 26 November 2019)

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