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Influence of resin cements on the final color determination of zirconia restorations on various core materials

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Influence of resin cements on the final color determination of zirconia restorations on various core materials

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더불어 대학원 수업에서 많은 학문적 자극과 지혜를 주셨던 정일영 교수님, 김의성 교수님, 박성호 교수님, 신수정 교수님께도 감사의 마음을 전합니다.

웃음과 감동으로 따뜻한 가르침을 주신 송병철 과장님과, 보존과 생활을 잘 할 수 있도록 이끌어 주신 김정희 부장님, 묵묵히 응원해 주신 김선호 과장님, 항상 따뜻한 조언을 해주신 김미연 과장님, 그리고 수련의들의 마음을 먼저 헤아려 주시는 김난아 과장님께도 감사드립니다. 그리고 우리 보존과 의국원들과 동기 수진이에게도 함께해 주어 고맙다는 말 전하고 싶습니다.

제가 하는 일이라면 뭐든지 믿어주고 응원해주시는 사랑하는 어머니, 아버지 그리고 누나를 늘 챙겨주는 든든한 동생, 문영이에게도 참 고맙습니다. 부족한 며느리이지만, 항상 배려해주시고 기도해주시는 사랑하는 어머님, 아버님께도 정말 감사드립니다. 마지막으로, 논문을 쓰는 과정 내내 옆에서 사랑으로 이해해주고 함께 공부하도록 저를 이끌어준 제 평생의 짝꿍 이신엽에게 사랑하는 마음과 고마운 마음을 함께 담아 전하고 싶습니다.

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Abstract

Influence of resin cements on the final color determination of zirconia restorations on various core materials

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1. Objectives

The goals of the present study were to compare translucency among different high-translucency monolithic zirconia products, and to investigate the effect of different resin cements on the final color of restorations used with different core materials.

2. Material and Methods.

Sixty zirconia discs were divided into 4 groups with a diameter of 10mm and thickness of 0.5mm and 1.0mm. (15 per groups; Lava Plus 0.5(LP 0.5), Lava Plus 1.0(LP 1.0), Lava Esthetic 0.5(LE 0.5), Lava Esthetic 1.0(LE 1.0)). Four types of core were fabricated with blue, white, A3 dentin shaded resin and titanium block with a diameter of 10mm and thickness of 5mm. Five self-adhesive resin cements were prepared with thickness of 25μm. Color measurement was used by spectrophotometer. The data are presented in L*, a*, and b* values. To test for significance in between-group differences, Tukey HSD test and one-way ANOVA were performed.

3. Results

Zirconia translucency was the highest in LE 0.5, followed by LP 0.5, LE 1.0, and LP 1.0. When the effect of core on zirconia color change is examined using LE 0.5, ΔE was the greatest in blue core, followed by metal, white, and A3 dentin shade resin core. All between-group differences were significant. ($p < 0.05$) When different zirconia and blue core was combined, ΔE was the greatest in LP 0.5, followed by LE 0.5, LP 1.0, and LE 1.0 with significant differences except for that between LE 0.5 and LP 1.0. ($p < 0.05$) When LE 0.5 and A3 dentin shade resin core are combined with different cement, ΔE value was the highest for G-Cem white, followed by TheraCem, U200A2, U200TR, and G-Cem A2. When LE 0.5 and blue core are combined with different cement, ΔE value was the highest for G-Cem white, followed by TheraCem, U200A2, G-Cem A2, and U200TR with significant differences. ($p < 0.05$)

4. Conclusions

Zirconia type and thickness made significant difference in translucency of high translucency monolithic zirconia product. The color change in the final restoration could be affected by the combination of certain core material and cement.

Keywords: monolithic zirconia; color; translucency; cement; spectrophotometer

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I. Introduction

The increased demand for esthetics in dental restoration has led to the use of ceramic system as an alternative to metal-ceramic restorative material.(Al-Amleh, et al., 2010; F. Wang, et al., 2013) In particular, the use of all-ceramic restorations has markedly increased, because they provide much greater esthetics than metal-ceramic restorations.(Yaman, et al., 1997) The utilization of all-ceramic restorations has further increased since the introduction of zirconia in the dentistry. The material has become an acceptable treatment modality in the restoration of the anterior as well as posterior teeth owing to the adequate mechanical characteristics and outstanding esthetics.(Guncu, et al., 2015)

When zirconia was first introduced, the approach was zirconia-based restoration, i.e., covering a zirconia core with a ceramic veneer. Compared to a metal-ceramic crown, however, veneered zirconium oxide typically has a problem of increased fracture rate due to mismatched thermal expansion rates, surface grinding, inadequate core design, and overloading.(Lawson and Burgess, 2014) To reduce the risk of veneering fracture and also to simplify restoration process, manufacturers have recently introduced monolithic zirconia restorations. (Lawson and Burgess, 2014)

The use of monolithic zirconia restorations in restorative dentistry is increasing due to compatible components, esthetic sensibility, simple clinical technique, and low cost relative to cast gold restorations.(Vagkopoulou, et al., 2009) Additional characteristics of monolithic zirconia restorations include natural tooth-like appearance, low corrosion potential, high biocompatibility, and low thermal conductivity.(Bressan, et al., 2011; Kohal, et al., 2008; Uzun, et al., 2007)

Also, due to its strong mechanical properties (flexural strength of about 900 to 1500MPa)(Conrad, et al., 2007), zirconia does not require the tooth to be ground down as much as glass-based all-ceramic crown.(Ilie and Stawarczyk, 2014) However, monolithic zirconia restorations have a weakness in esthetics due to lower translucency in comparison to ceramic restorations.(Church, et al., 2017) It is because opacity increases with the size of crystalline particles, which induces more light scattering and reduces translucency so that less light passes through the material.(Sulaiman, et al., 2015)

Dental manufacturers and laboratories gradually improved the weakness and have recently been marketing high-translucency monolithic zirconia restorative materials that have high esthetic value and excellent strength properties.(Church, et al., 2017) Such monolithic zirconia ceramic materials are an alternative to satisfy the needs of both patients and dentists by providing higher translucency without sacrificing strength properties(Church, et al., 2017)

Of the high-translucency monolithic zirconia products recently launched in market, Lava™ Plus High Translucency Zirconia is 3Y-TZP (3 mol% yttria partially stabilized tetragonal zirconia polycrystal) and contains cubic phase zirconia under 15%. As Lava plus is made of colorless blocks, to make the color of natural teeth, in this study, dipping liquid was used to create actual shade. Meanwhile, Lava™ Esthetic Fluorescent Full-contour Zirconia is 5Y-PSZ (5 mol% yttria partially stabilized zirconia) and contains cubic phase zirconia over 50%.(Zhang and Lawn, 2018). Unlike Lava Plus, as Lava esthetic contains a shade in the block itself, dipping process is not required. Also, it is said that the gradation of color as the natural teeth can be reproduced.

For the improvement of optical properties, the translucency parameter (TP) value of Lava Plus is significantly higher in comparison with other zirconia ceramic products, including two other Lava products (Lava Standard and Lava Standard FS3), showcasing the improved optical properties of newly developed zirconia ceramic products.(F. Wang, et al., 2013)

With respect to strength properties, flexural strength is over 1200MPa in Lava Plus and over 800MPa in Lava Esthetic, both exceeding ISO6872:2015 limit for a Type II, Class 4 indication. It has been argued based on the finding that the minimal occlusal wall thickness in the posterior is likely to be 0.5mm in Lava Plus and 0.8mm in Lava Esthetic(Bjorn Theelke, 2017)

Many studies have found a strong inverse association between thickness and translucency value.(Bagis and Turgut, 2013; Della Bona, et al., 2015; Lee, 2007; Shokry, et al., 2006)) Sulaiman et al. found a brand-dependent, inverse relationship between thickness and translucency in monolithic zirconia products.(Sulaiman, et al., 2015)

Kim and Kim suggested that precolored monolithic zirconia ceramic may cause color mismatch due to high L* and low a* and b* values.(Kim and Kim, 2016) Tabatabaian et al. stated that if the treatment option is monolithic zirconia restoration on an A4 shade foundation material or a prepared tooth (with dentin color), thickness of the restorative material should be at least 0.9mm to attain an acceptable final color, in consideration of the size of the foundation and/or the amount of tooth removal.(Tabatabaian, et al., 2018b)

Translucency of a porcelain is typically expressed as CR and/or TP. TP is defined as the color difference (ΔE) in a material of a certain thickness against black and white backings.(Johnston, et al., 1995) A TP value under 2.0 is considered sufficiently opaque to cover black background.(Y. Chaiyabutr, et al., 2011)

Many studies have quantified color differences using Commission Internationale de I'Eclairage (CIELAB) color space and associated color difference equations. However, the outcome would have no value without a reference threshold to compare with,(Al Hamad, et al., 2018) and thus, a threshold against which to compare an observed color difference should be established.

Color is measured with spectrophotometer, the most precise and flexible instrument for color matching currently used in dentistry.(Chu, et al., 2010) The instrument can detect a minuscule difference in color that human eye cannot detect. A perceptible but clinically acceptable threshold can be defined by referring to ΔE values.(Vichi, et al., 2011)

Zirconia is usually cemented using dual cure cement. Dual cure resin cement is cured by both light and chemical curing systems. This type of cement is used where light does not easily pass through, because the self-curing component polymerizes even the underneath of a restorative material making it too thick or very opaque. However, color shift may occur during aging, since the type of cement contains tertiary amine benzoyl peroxide as an initiator. With respect to color stability, light curing cement has an advantage over dual cure resin cement,(Kilinc, et al., 2011) but color shift may still occur due to unpolymerized camphoroquinone photoinitiator where it is difficult for light to pass. Accordingly, dual cure resin cement is the most acceptable option for opaque and thick restorative material.(Sunico-Segarra and Segarra, 2015). In addition, light activation of dual-cure resin cement is reported to offer a better mechanical property than relying on self-cure activation does.(Ilie and Stawarczyk, 2014)

The color of resin cement can influence the final color of zirconia restoration, as well. Masking ability of zirconia is known to have to do with the color coverage of underlying substructures including cement and dental substrate.(Vichi, et al., 2000) The colors of underlying tooth, abutment, and luting cement can all affect the final color of ceramic restoration as much as the material itself. The color of cement can be influential, if a dental ceramic is thinner than 1.5mm and if a restorative material is placed over a dark underlying tooth, or used to cover discoloration or prevent a displeasing outcome.(Chang, et al., 2009) Jankar et al. reported that opaque cement lightens the shade of a ceramic veneer, whereas transparent cement darkens it.(Jankar, et al., 2015) Thickness of resin cement also has an effect on the final color of ceramic restoration.(Yada Chaiyabutr, et al., 2011)

Regarding cement-induced color change in the final restoration, some studies argued that a cement having a different shade from the ceramic material may result in a perceptible color difference in a veneer restoration.(Turgut and Bagis, 2013; Xing, et al., 2010) But according to

Vichi (Vichi, et al., 2000) et al. and Azer(Azer, et al., 2006) et al., resin cement does not influence the final color of the IPS Empress all-ceramic material.

As discussed above, as zirconia translucency increases, it may be more difficult to match colors in the final restoration. Therefore, the colors of an abutment beneath a zirconia restoration and a cement should be very carefully chosen. However, the effect of resin cement in varying colors on the final color of a zirconia restoration, particularly a high-translucency monolithic zirconia restoration (a product with improved translucency), has so far never been clearly established.

Accordingly, the goals of the present study were to compare translucency among different high-translucency monolithic zirconia products, and to investigate the effect of different resin cements on the final color of restorations when the esthetically pleasing products are used with different core materials.

The null hypotheses of the study were as follows. First, there would be no significant difference in translucency of high-translucency monolithic zirconia products according to product type or thickness. Second, color of the high-translucency monolithic zirconia products would not be changed by the core material used underneath the products. Third, final color of a restoration would not be changed when high-translucency monolithic zirconia products are used in combination of a variety of core materials and luted by a variety of resin cements.

II. Material & Methods

1. Zirconia specimen preparation

A computer-aided design and computer-aided manufactured(CAD-CAM) system (Rhinoceros 5 CAD program; Rhinoceros 5 SR 13; Robert McNeel & Associates, Seattle, Washington, USA) was employed to design zirconia discs (Lava™ Plus High Translucency Zirconia Disc, Lava™ Esthetic Fluorescent Full-Contour Zirconia Discs; 3M ESPE, St Paul, MN, USA) with a diameter of 10mm and thickness of 0.5mm and 1.0mm.(Table 1) Zirconia blocks were milled by using Roland milling machine which was set by CAM software(hyperDENT; Open Mind Technologies AG, Wessling, Germany). Sixty zirconia discs were divided into 4 groups, Lava plus 0.5mm, Lava plus 1.0mm, Lava esthetic 0.5mm, and Lava esthetic 1.0mm (n=15, each). After milling was completed, specimens were cut from connector and then trimmed. Specimens were contained in sintering box and sintered according to the manufacturer's recommendations. Lava Plus specimens were colored with an A2 shade dyeing liquid (3M™ESPE™ Lava™ Plus High Translucency Zirconia Dyeing liquid A2) and dried for 45miniutes under a lamp. An A2 shade block was used for Lava Esthetic. Because it is manufactured in that shade, a dipping process was not performed. The specimens were sintered at a maximum temperature of 1520℃ for 12 hours in a sintering furnace.

Zirconia discs were polished with sequentially 600-,800-,1000-, and 1200 grit silicon carbide abrasive papers in a polishing machine under water cooling to obtain a certain thickness (0.5±0.02mm, 1.0±0.02mm). A digital micrometer (293 MDC-MX Lite; Mitutoyo Corp., Tokyo, Japan) with an accuracy of 0.002mm was employed to measure the thickness of discs. Only one surface of the disc was polished to reproduce the clinical situation.

2. Core disks preparation

Four types of core were fabricated with blue shaded dual cure resin(Core-flo DC; Bisco Inc., Schaumburg, IL, USA), white shaded dual cure resin(Core-flo DC; Bisco Inc), A3 dentin shaded composite resin(FiltekZ350 A3 dentin; 3M ESPE, St. Paul, MN, USA) and titanium block(Osstem TS Pre-milled abutment; Osstem Implant, Seoul, Korea) (Table 1). Acryl plate were prepared with the hollow space of 10mm diameter, 5mm height to fabricate the mold of resin core. Blue core resin and white core resin were applied to the mold with the bottom of mylar strip. When the core was filled up to 5mm, mylar strip was placed on the top of the core resin. Then, 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 800mW/cm^2. A3 dentin shaded composite resin was applied incrementally and light-cured every 2mm with the curing unit as described above. Resin core was polished with sequentially 600-,800-,1000-, and 1200grit silicon carbide abrasive papers in a polishing machine. Titanium core was fabricated with custom made with Osstem titanium abutment block (Osstem TS Pre-milled abutment) with 10mm diameter and 5mm thickness. The same micrometer was used to measure the thickness of core(5.0 ±0.02mm).

3. Cement disk preparation

Five different dual-cure, self-adhesive resin cements were prepared(Table 1). Each cement was mixed according to the manufacturer's recommendations. Except one brand, G-Cem(G-CEM One; GC Corp, Tokyo, Japan) the mixture of resin cement was applied between two polyester strips under hard transparent plate with pressure of 9.8N (Tabatabaian, et al., 2016) and polymerized with a polymerizing light unit(Dentsply SmartLite Pen Style LED curing light) at 800mW/cm^2 for 20 seconds on each side. G-Cem one white and A2 were used with optional tooth primer which is called by G-Cem one adhesive enhancing primer. Tooth primer was applied to polyester strip with microbrush according to the manufacturer's recommendations, then dried with 3-way syringe. Then, the mixture of G-Cem one cement was putted on the dried primer. Subsequent process was equal to the other cements. The cured cement was trimmed with blade following the shape of core resin.

The thickness of cement was adjusted with polishing procedure. Until the thickness is fitted in intended range(25 μm ±0.02), cured cement specimen was polished, and subsequently, measured by digital micrometer.

4. Translucency calculation

Zirconia translucency was elicited by comparing the value when the zirconia specimen was on the black background and white background. Translucency parameter(TP) value represents the translucency of different thickness and type of zirconia specimens. TP value was also calculated from the formula. TP = $[(L^*_B - L^*_W)^2 + (a^*_B - a^*_W)^2 + (b^*_B - b^*_W)^2]^{1/2}$. L* : brightness, a* : redness to greenness, b* : yellowness to blueness, B : black background, W : white background.

5. Color measurement

Color measurement was used by handy spectrophotometer (Vita EasyShade® V; Vita Zahnfabrik, Bad Säckingen, Germany). A silicon putty index (3M ESPE Express™ STD; 3M ESPE) was fabricated to maintain the equal condition despite differing the used material and to avoid external light.(Tabatabaian, et al., 2018c),(Tabatabaian, et al., 2017). Color measurements of all specimens were provided on white background. First, to examine the masking ability of zirconia, the differences between the value measured with zirconia on white background and the value measured with the specimens on each of the 4 types of core material as a backing (zirconia+core) were computed. Second, to examine cement-induced color change, color measurement were conducted before cementation(zirconia specimens were placed on the different core materials; zirconia+core), and accompanying with cement specimens(zirconia+cement+core). To provide optical connection, distilled water was applied every measurements between each layer.

The data are presented in L*, a*, and b* values according to CIE (Commission International de l'Eclairage or International Commission on Illumination).

ΔE values were calculated using the formula:

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

Vichi et al.(Vichi, et al., 2004) used 3 different ranges in differentiating color shifts. A ΔE value under 1.0 is considered undetectable by human eye, and a ΔE value between 1.0 and 3.3 is considered visible by skilled operators but still clinically acceptable. A ΔE value over 3.3 is not clinically acceptable, because it is appreciable by a non-skilled person.

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

6. Statistics analysis

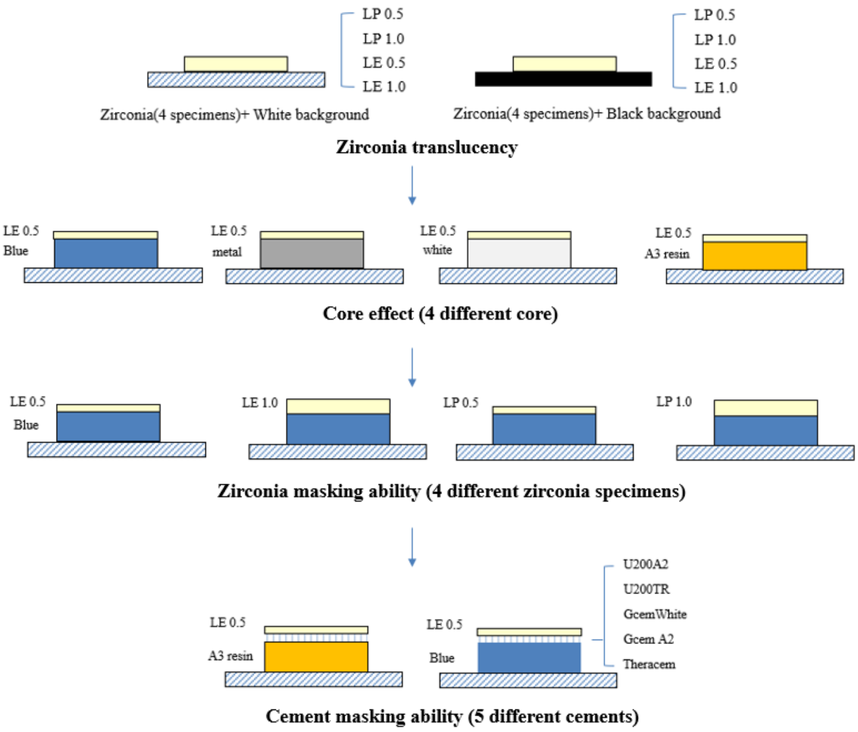
Statistical analysis were performed using the R statistical software, version 3.5.1. (R development Core Team; R Foundation for Statistical Computing, Vienna, Austria)

To test for significance in between-group differences, Tukey HSD test and one-way ANOVA were performed. (p = 0.05)

Table 1. Materials used in this study.

	Materials	Manufacturer	Lot number	Diameter	Thickness
Zirconia					
LP 0.5	Lava™ Plus	3M ESPE St Paul, MN, USA	669344	10mm	0.5mm
LP 1.0	High translucency zirconia				1.0mm
LE 0.5	Lava™ Esthetic		3994896		0.5mm
LE 1.0	Fluorescent Full-Contour Zirconia				1.0mm
core					
Blue	Core-Flo™ DC Blue	Bisco, Inc. Schaumburg, IL, USA	1800002442	10mm	5mm
metal	Osstem TS Pre-milled abutment	Osstem, Seoul, Korea	PTA18F234		
white	Core-Flo™ DC Opaque white	Bisco, Inc. Schaumburg, IL, USA	1700003296		
A3 dentin shade	Filtek Z350	3M ESPE St Paul, MN, USA	N718626		
cement					
U200A2	RelyX™ U200 Automix Self-adhesive resin cement	3M Deutschland GmbH	3722465	10mm	0.025mm
U200TR			671502		
G-Cem white	G-Cem One Adhesive resin cement	GC Corporation Tokyo, Japan	1802082		
G-Cem A2			1802082		
TheraCem	TheraCem™ Self-adhesive resin cement	Bisco, Inc.Schaumburg, IL, USA	1800002483		

Fig 1. Flowchart of this study



III. Results

1. Zirconia translucency

To standardize zirconia thickness, mean thicknesses and significance in between-group differences were examined. The difference between Lava Plus 0.5 (LP 0.5) and Lava Esthetic 0.5 (LE 0.5) was not significant, neither was the difference between Lava Plus 1.0 (LP 1.0) and Lava Esthetic 1.0 (LE 1.0). T-test was performed to test for significance of between-group differences.

	Mean TP	min	max	95% CI
LE 0.5 (n=15)	25.86 [a]	24.23	28.23	(25.23-26.49)
LP 0.5 (n=15)	23.51 [b]	22.19	24.76	(23.11-23.91)
LE 1.0 (n=15)	17.36 [c]	16.18	19.91	(16.79-17.93)
LP 1.0 (n=15)	14.91 [d]	14.26	16.06	(14.62-15.2)

Table 2. Data on zirconia translucency. (n=15, Each) To test between-group difference, Tukey HSD was performed. Different lowercase letters indicate differences between zirconia translucency. (in column) ($p < 0.05$)

Zirconia translucency was the highest in LE 0.5, followed by LP 0.5, LE 1.0, and LP 1.0. Tukey HSD conducted to test for significance of between-group differences showed that all between-group differences were significant. The thinner the zirconia, the higher the translucency. And, translucency was greater in LE compared to LP at the same thickness. Translucency was influenced by both thickness and product type.

2. The effect of core on zirconia color change

		Blue (n=15)	Metal (n=15)	White (n=15)	A3_resin (n=15)
LE 0.5	ΔE	38.08 ± 1.03 [a]	33.66 ± 1.22 [b]	20.91 ± 1.65 [c]	14.85 ± 1.18 [d]

Table 3. Difference between LE 0.5 by itself and LE 0.5 combined with each of the 4 core materials. All specimens were measured above white background. Different lowercase letters indicate differences between core materials (in rows) ($p < 0.05$)

It was reasoned that core-induced color change would be the greatest in LE 0.5, because it showed the highest level of translucency. Thus, the effect of core in zirconia color change was examined using LE 0.5. The ΔE values for color change were computed by using the formula using the L, a, and b values for LE 0.5 alone and the corresponding values for LE 0.5 combined with each of 4 core types. All measurements were done in white background. The results showed that ΔE was the greatest in blue core, followed by metal, white, and A3 dentin shade resin core. All between-group differences were significant on the basis of Tukey HSD test.

3. ΔE of the combination of a zirconia product and blue resin core according to zirconia thickness and type

	LP 0.5 (n=15)	LE 0.5 (n=15)	LP 1.0 (n=15)	LE 1.0 (n=15)
ΔE	41.82 ± 2.04 [a]	38.08 ± 1.03 [b]	37.53 ± 2.65 [b]	34.74 ± 2.05 [c]

Table 4. Color difference between zirconia by itself and zirconia combined with a blue core. All specimens were measured above white background. Different lowercase letters indicate differences between core materials (in rows) ($p < 0.05$)

When a zirconia was combined with various core materials, blue core induced the greatest color shift. Thus, to investigate masking effect of zirconia on a core, color change was examined with zirconia specimens alone and with the specimens combined with blue core. All measurements were conducted on white background.

ΔE was the greatest in LP 0.5, followed by LE 0.5, LP 1.0, and LE 1.0. Tukey HSD test was conducted to test between-group differences, and the results showed that all between-group differences were significant, except for that between LE 0.5 and LP 1.0.

4. △E of the combination of LE 0.5 and A3 dentin shade resin core according to cement type

		GCem white (n=15)	TheraCem (n=15)	U200A2 (n=15)	U200TR (n=15)	GCem A2 (n=15)
A3 resin	ΔE	5.92 ± 1.80 [a]	3.82 ± 2.55 [b]	2.99 ± 1.18 [c]	2.90 ± 1.56 [d]	1.83 ± 1.01 [e]

Table 5. Color difference between LE 0.5 (n=15) combined with A3 dentin shade resin and the combination with each of 5 resin cement types. All specimens were measured above white background. Different lowercase letters indicate differences between core materials (in rows) ($p < 0.05$)

To identify the type of cement which can be used to achieve the most adequate color in a zirconia restoration on a prepared tooth, color change in the final restoration was examined by varying cement type in the combination of LE 0.5 and A3 dentin shade resin core, which had a color similar to the tooth. The ΔE value was the highest for G-Cem white, followed by TheraCem, U200A2, U200TR, and G-Cem A2. Tukey HSD test showed that all between-group differences were significant.

5. ΔE of the combination of LE 0.5 and blue core according to cement type

		Gcem white (n=15)	TheraCem (n=15)	U200A2 (n=15)	Gcem A2 (n=15)	U200TR (n=15)
blue	ΔE	28.95 ± 1.43 [a]	19.99 ± 1.24 [b]	11.77 ± 1.55 [c]	10.45 ± 1.17 [d]	10.38 ± 1.20 [e]

Table 6. Color difference between the combination of LE 0.5 (n=15) and blue core resin and the combination luted with each of the 5 resin cement types. All specimens were measured above white background. Different lowercase letters indicate differences between core materials (in rows) ($p < 0.05$)

Of the core materials, blue core induced the greatest color change. Accordingly, to identify the most proper cement to mask the color of the structure underneath a restoration, L*, a*, and b* values were computed for the combination of LE 0.5 and blue core alone and when each of the 5 cement types was used on the combination. All measurements were conducted on white background. The ΔE value was the highest for G-Cem white, followed by TheraCem, U200A2, G-Cem A2, and U200TR, and Tukey HSD test showed that all between-group differences were significant.

IV. Discussion

Lava Esthetic 0.5 had the highest translucency. The next highest was Lava Plus 0.5, followed by Lava Esthetic 1.0, and Lava Plus 1.0. All differences among the 4 zirconia specimens were significant. The thinner the zirconia, the higher the translucency, and translucency was higher in a Lava Esthetic than in a Lava Plus of the same thickness. Thus, the first null hypothesis was rejected.

With respect to color change in various combinations of zirconia and core, the change was the greatest in all zirconia specimens when combined with blue core, followed by metal, white, and A3 dentin core. Tukey HSD test and one-way ANOVA showed that all between-group differences were significant. Thus, the second null hypothesis was rejected, as well.

Blue core induced the greatest color change in all combinations of zirconia and core. To examine masking ability of zirconia, color change was observed with a zirconia specimen alone or combined with a blue core. Color change was the greatest in Lava Plus 0.5, followed by Lava Esthetic 0.5, Lava Plus 1.0, and Lava Esthetic 1.0. The difference between Lava Esthetic 0.5 and Lava Plus 1.0 was not significant, but all other between-group differences were significant. In this study, the measurements of translucency showed that Lava Esthetic specimens had higher translucency in comparison to Lava Plus specimens with the same thickness. Therefore, results on masking effect were anticipated to be opposite to the translucency finding. However, the results showed that Lava Esthetic 1.0 had a significantly higher masking ability than any other specimen, and that Lava Plus 1.0 and Lava Esthetic 0.5 were similar, with Lava Plus 0.5 showing the lowest masking ability. It could be speculated that the reason why Lava Plus had lower masking ability than Lava Esthetic is that both Lava Plus and Lava Esthetic are a high-translucency monolithic zirconia and variations in masking ability among different zirconia products could be small when a core material causing a large color change, like blue core, is used. Additionally it is believed that in zirconia products of similar translucency, it is thickness, rather than brand, that primarily affects masking effect. Also, it may speculate that the reason the relationship between translucency and masking ability is not a direct inverse correlation and it may be associated with the difference in color reproduction process of zirconia block. As, Lava Plus is colored with dipping liquid, but Lava esthetic has own shade from its block before sintering.

Color change in the final restoration was examined in the combination of LE 0.5 and A3 dentin shade resin (i.e., the core in a color similar to the tooth) by varying cement type. The ΔE value was the highest for G-Cem white, followed by TheraCem, U200A2, U200TR, and G-Cem A2, and all between-group differences were significant. Color change was clinically unacceptable when G-Cem white and TheraCem (G-Cem white : 5.92 ± 1.80, TheraCem : 3.82 ± 2.55) were used. Accordingly, the third null hypothesis was rejected. When a core in a color similar to the tooth is used, a lower ΔE value indicates a smaller color change, while a higher ΔE value indicates a greater masking effect of the resin cement. Hence, if an A2 shade high-translucency monolithic zirconia is cemented on a prepared tooth using an opaque cement like G-Cem white and TheraCem, the final color of the restoration may be too light. All other cements resulted in a color change in the clinically acceptable range, and differences among them are expected to be clinically insignificant.

To identify the cement most adequate in masking the color of an abutment, Lava Esthetic 0.5 was combined with a blue core using each of the 5 cement types and ΔE values were computed. The value was the highest for G-Cem white, followed by TheraCem, U200A2, G-Cem A2, and U200TR. A higher ΔE of a combination using a blue core suggests a greater masking effect. In all 5 cement types, the ΔE value was over 3.3, indicating that color difference is sufficiently detectable by human eye. However, masking effect was significantly high only in opaque cements, i.e., G-Cem white and TheraCem, and was the lowest in U200TR.

Optical effect of luting cements in the final color of restorations has been investigated in many previous studies. Some studies reported that the effect was insignificant, while some others demonstrated that the color of luting cements significantly influences the final color of translucent restorative materials.(Vichi, et al., 2000),(Azer, et al., 2006) In regard to optical characteristic and color, cements are classified as shaded, bleached, opaque, or transparent.(Alqahtani, et al., 2012) Opaque cement makes the shade lighter, whereas transparent cement makes it darker due to change in L* value.(Tabatabaian, et al., 2018a)

Dede et al.(Dede, et al., 2017b) showed that white opaque cement group had significantly higher ΔE values compared to other groups in both types of lithium disilicate block and that clinically unacceptable color change occurred in white opaque cement group.

In another study, Dede(Dede, et al., 2017a) suggested that both brand and shade of the resin cements significantly influenced the final color of the restorations. Specifically, the universal shade tended to change the color toward yellow (positive a) and the translucent shade toward blue (negative b). In this present study, the combination of Lava Esthetic 0.5 and a blue core had the smallest ΔE when cemented with U200TR, it can be thought that the final color was shifted further to blue because of U200TR.

A clinical purpose of using white and/or opaque cement is either to cover an unwanted color of the underlying substrate or to correct the final color of a restoration.(Chang, et al., 2009; Dede, et al., 2013; Xing, et al., 2010) According to Uzun et al.(Uzun, et al., 2007) white opaque cement can be used to mask the color of a metallic abutment. Other relevant studies have shown that white and/or opaque cement ultimately improves the color of a restoration specifically if the background color is dark.(Chang, et al., 2009; Dede, et al., 2013; Turgut and Bagis, 2013; Uzun, et al., 2007)

Thus, it is concluded that white opaque cement will result in a much lighter color if the tooth and the restorative material are similar in color, although it is appropriate to use it to cover a substructure in a darker color. Of course, the effect of cement color may have been stronger in the aforementioned studies because the restorative materials used in the studies have higher translucency than monolithic zirconia.

A ΔE value under 1.0 is regarded as undetectable by human eye, while a value between

1.0 and 3.3 is considered visible to qualified operators but clinically acceptable. If a ΔE value is 3.3 or higher, the difference is visible and hence, it is clinically unacceptable.(Ruyter, et al., 1987),(Alqahtani, et al., 2012),(Dozic, et al., 2010) Douglas et al., however, have defined the ΔE value of 2.6 as perceptibility limit, the ΔE value of 5.5 as acceptability tolerance, and a ΔE value under 3.7 as clinically acceptable.(Douglas, et al., 2007) In the present study, the threshold to detect color change was setted to ΔE values of 3.3, which was used in many previous studies.

According to Heffernan, Chang, Kelly, and other researchers,(Chang, et al., 2009),(Heffernan, et al., 2002),(Kelly, et al., 1996) the property of translucency/opacity is the most critical factor in the selection of materials, and an essential factor to satisfy esthetic needs.

The TP of dental ceramic is significantly influenced by both thickness and type. In all materials, translucency increases as thickness decreases, but the amount of change is material-dependent.(F. Wang, et al., 2013) Kanchanavasita et al.(Kanchanavasita, et al., 2014) stated that to compare various brands on translucency, all specimens should be milled to the same thickness and showed that thickness significantly influenced translucency in an inverse relationship of increase in translucency as thickness decreased. Hence, in the present study it was determined to observe the effect of zirconia translucency while controlling the thickness of zirconia specimens at a constant level, within a range of statistical insignificance.

Chaiyabutr et al.(Y. Chaiyabutr, et al., 2011) observed that most studies investigated translucency of dental ceramic at a specific thickness, generally with the thinnest recommended by the manufacturer. Accordingly, the current experiment was conducted by setting zirconia thickness at the manufacturer recommended minimal thickness of 0.5mm and the mean thickness of 1.0mm.

According to Church et al.,(Church, et al., 2017) very translucent zirconium oxide material is not as translucent as lithium disilicate, but high-translucent zirconia material at the clinically considered minimal thickness is as translucent as lithium disilicate. Moreover, flexural modulus and flexural strength is significantly greater in high-translucent zirconia materials compared to lithium disilicate. Given these, the level of translucency comparable to that of lithium disilicate could be gained by using zirconia with minimal tooth removal.

In Yu et al.,(Yu, et al., 2009) the TP of human dentin was 16.4 and that of enamel was 18.1 at the thickness of 1.0mm, similar to the TP of glass ceramic (14.9-19.6). According to Wang et al.,(Fu Wang, et al., 2013) the TP of monolithic zirconia was 5.5–13.5 at 1.0mm thickness, especially TP of Lava plus high translucency zirconia was 13.5, which is also lower compared to human dentin. Sulaiman et al.,(Sulaiman, et al., 2015) reported that the range of TP values of 1.0mm zirconia in their specimen group was 11.16–15.3, still lower than the TPs of enamel and dentin, and concluded that many improvements would be needed for zirconia to optimally match with natural teeth. But in the present study, the TP values of zirconia 1.0mm were much higher, with 14.91 for Lava Plus and 17.36 for Lava Esthetic. Thus, the TP of Lava Esthetic was higher compared to human dentin of the same thickness, but lower compared to human enamel. Change in the crystal structure of zirconia is believed to have contributed much to improved translucency.

Zirconia exists in three crystallographic polymorphs. The monoclinic phase (m) is stable at room temperature and the tetragonal phase (t) is stable between 1170°–2370°. In contrast, zirconia in the cubic phase is a high-temperature structure.(Hannink, et al., 2000) The increased translucency of Lava Esthetic in particular can be said to be achieved by controlling crystalline phase. Translucency increases if the amount of the cubic phase increases and that of the tetragonal phase decreases, because the cubic phase prevents light scattering from the grain boundary.(Zhang, et al., 2012) The amount of the cubic phase increases as the yttria level increases, consequently improving translucency.(Jiang, et al., 2011)

Increased translucency in zirconia is achieved from structural change due to increased yttria content from 3 to 5mol%. The tetragonal zirconia phase further reduces cubic phase particles, resulting in decreased flexural strength (600-800MPa).(Blatz, et al., 2016) Y-TZP stabilized with 5.18 wt% yttria has 90% or more tetragonal phase, but to produce translucent zirconia, the yttria concentration should increase to 7wt% or higher.(Zhang, 2014) It has been reported that integration with a mean grain size under 80nm can make 75% tetragonal-25% cubic phase, and a porosity content under 0.01% can produce a translucent zirconia ceramic.(Zhang, 2014) Moreover, translucency can be increased to an ultra level if the cubic phase is 50%. Reduction in grain size and increase in the cubic phase may, however, weaken flexural strength and fracture toughness of zirconia.(Matsuzaki, et al., 2015)

Tabatabaian et al. investigated the thickness of zirconia coping needed to mask color change in a variety of restorative materials and reported that the thickness for an ideal masking ability was 0.4mm in A1 shade composite resin, A3.5 shade composite resin, A3 shade Zirconia, and non-precious gold-colored alloy, 0.6mm in amalgam, and 0.8mm in nickel-chromium alloy.(Tabatabaian, et al., 2018c) In a clinical situation with an existing core, options are available to compensate for the effect of the background, such as using an opaque cement, increasing the veneering porcelain thickness, or using a proper thickness of zirconia coping.(Tabatabaian, et al., 2018c)

Best luting agent should be used to gain a high bond strength with cementation. Resin cement has been preferred in all-ceramic restorations due to its low solubility, good esthetics, and high bond strength.(Linden, et al., 1991) Also, it is used to adjust the final color of a restoration and mask the color of the substructure.(Chang, et al., 2009),(Dede, et al., 2013) Dual-cure resin luting agents have been developed as an attempt to combine the ideal properties of self-cure and light-cure resin cements. The chemical curing components guarantee complete polymerization in the deep cavity floor, while photo-activation ensures immediate finishing after an exposure to curing light.(Hofmann, et al., 2001)

As shown above, opaque cement can be used to mask a dark/metal/discolored background, but ceramic thickness should be increased to compensate for the cement's color. Moreover, depending on the targeted color, a cement in a color similar to the tooth to be restored is an option for tooth-colored background to achieve color harmony among cement, background, and ceramic.

Such choice can effectively decrease the need to increase ceramic thickness.(Tabatabaian, 2018)

Rosenstiel et al reported that film thickness of the luting agent can directly affect long-term clinical success.(Rosenstiel, et al., 1998) According to American Dental Association(ADA), a maximum film thickness of 25 µm is allowed for a Type I cement, which is designed for accurate seating of precision appliances and for other uses. ADA type II materials which are recommended for all uses except the cementing of precision appliance can have maximal film thickness of 40 µm.(Materials and Devices, 1978) Leinfelder et al suggested that the interfacial gap should not exceed 100µm, particularly on the occlusal surface since wider gaps commonly may result in extensive wear of the composite resin luting agent.(Leinfelder, et al., 1989) Therefore, in this study, resin cement thickness was set for Type I cement (25 µm).

There are a few limitations in the study. First, variables regarding aging-induced color change were not considered. With aging, zirconia may show change in translucency, which has to do with tetragonal-to-monoclinic phase transformation. Incremental change in Y-TZP's microstructure over aging may be related to change in reflection of the monoclinic crystal itself as well as change in light reflection of the monoclinic and tetragonal crystals. Furthermore, the surface porosity in the region of phase transformation can change (microcrack) due to change in the volume of the monoclinic crystal, influencing translucency.(Fathy, et al., 2015) Also, the colors of cement and resin core are expected to change with aging. Specifically, it is expected that the color of resin based materials may shift further to yellow due to water absorption of such components as TEG-DMA and Bis-GMA and that the color may also change due to uncured camphorquinone depending on the polymerization rate.

Second, in the experiment the specimens did not undergo the process of direct cementation. With direct cementation, light reflection and refractive index would have been different, exerting different influences on translucency and color changes and producing outcomes different than the in vivo experiment.

Third, the cements used in the experiment tended to be thin. A typical thickness of resin cements used in many previous studies is 100µm, thicker than what was applied in the present experiment. The effect on color change may have been smaller in this study because the resin cements were thinner. The thickness used in the current experiment, 25µm, is the criterion applied for precise restoration such as inlays and onlays. Accordingly, it is speculated that if the cement is thicker, masking effect may be stronger and masking ability of different cement types may differ.

Lastly, zirconia thicknesses in this experiment were what the manufacturer determined as the minimal (0.5mm) and the mean (1.0mm) of Lava Plus. The minimal thickness of Lava Esthetic determined by the manufacturer is 0.8mm. Hence, the thickness of Lava Esthetic specimens used in the experiment may have a greater impact on color change than the clinically used product does. In addition, comparisons of a larger range of thickness, up to 2.0mm, would have produced clinically more useful findings.

V. Conclusion

Within the limitations of the study, the following conclusions can be derived.

1) Zirconia type and thickness made significant difference in translucency of high translucency monolithic zirconia product.

2) Color of the high-translucency zirconia products was changed by the core material. The amount of color change in the final restoration was in the order of blue> metal> white> A3 dentin

3) Final color of a high-translucency zirconia restoration was changed by combination of certain core materials and resin cements. Opaque white cement showed high masking ability, but not to the extent to which it could completely cover a dark core.

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Abstract (In Korean)

다양한 코어 재료에 대한 지르코니아 수복물의 최종 색상 결정에 대한 레진 시멘트의 영향

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I. 목적

본 연구의 목적은 high translucency monolithic zirconia의 translucency를 비교하고, resin cement가 수복물의 최종 색조에 미치는 영향을 알기 위함이다.

II. 방법 및 재료

육십개의 A2 shade high translucency monolithic zirconia 디스크가 지름 10mm, 두께는 0.5mm와 1.0mm로 제작되어 4개의군으로 나눠졌다. (n=15, Lava Plus 0.5(LP 0.5), Lava Plus 1.0(LP 1.0), Lava Esthetic 0.5(LE 0.5), Lava Esthetic 1.0(LE 1.0)) Core는 blue, white shade의 dual cure resin, A3 dentin shade의 composite resin, 그리고 titanium block을 이용하였고 지름은 10mm, 두께는 5mm로 제작하였다. Cement는 5종류의 self adhesive resin cement로, 두께는 25 마이크로 미터로 제작하였다.

색조의 측정은 spectrophotometer를 사용하여 L*, a*, 그리고 b*값을 측정하였다. 통

계학적 유의차 알기 위해 tukey HSD test와 one-way ANOVA가 시행되었다.

III. 결과

지르코니아 투과도 측면에서는 LE 0.5>LP 0.5> LE 1.0> LP 1.0순으로 나타났고, 각 군 간의 유의차 존재하였다. LE 0.5에 core를 다르게 하여 색변화를 관찰하였을 때, blue, metal, white, A3 shade resin 순으로 색변화 크게 나타났다. 각 군 간에 모두 유의차 존재하였다. core를 blue로 하였을 때, 각 지르코니아 종류별 색변화를 관찰하였다. 이때 색 변화는 LP 0.5, LE 0.5, LP 1.0, 그리고 LE 1.0 순으로 가장 큰 색 변화가 나타났다. 이때 LE 0.5와 LP 1.0간에는 유의차 존재하지 않았고 나머지 군 간에는 모두 유의차 존재하였다. LE 0.5에 core를 A3 dentin shade resin을 사용하였을 때, cement로 인한 색 변화는, 가장 큰 것은 Gcem white였고, Theracem, U200A2, U200TR, GcemA2 순이었다. LE 0.5에 blue core를 사용했을 때 cement로 인한 색 변화를 관찰하였다. 이때 가장 큰 색 변화는 Gcem white였고, 그 다음으로 theracem, U200A2, Gcem A2, U200TR순으로 나타났다. 모든 군 간에 유의차 존재하였다.

IV. 결론

지르코니아 두께가 두꺼울수록, 투과도는 감소하였다. Zirconia 최종 수복물의 색은 특정한 core재료와 cement의 조합에 의해 영향을 받았다. core 재료를 다르게 했을 때, blue>metal> white> A3 dentin순으로 최종 수복물에서의 색 변화가 더욱 큰 값으로 나타났다. 비교적 opaque 계열의 cement가 masking능력이 더욱 컸다.

핵심되는 단어: monolithic zirconia; color; translucency; cement; spectrophotometer