Evaluation of the color reproducibility of all-ceramic restorations fabricated by the digital veneering method

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PURPOSE. The objective of this study was to evaluate the clinical acceptability of all-ceramic crowns fabricated by the digital veneering method vis-à-vis the traditional method. **MATERIALS AND METHODS.** Zirconia specimens manufactures by two different manufacturing method, conventional vs digital veneering, with three different thickness (0.3 mm, 0.5 mm, 0.7 mm) were prepared for analysis. Color measurement was performed using a spectrophotometer for the prepared specimens. The differences in shade in relation to the build-up method were calculated by quantifying ΔE^* (mean color difference), with the use of color difference equations representing the distance from the measured values L*, a*, and b*, to the three-dimensional space of two colors. Two-way analysis of variance (ANOVA) combined with a Tukey multiple-range test was used to analyze the data (α=0.05). **RESULTS.** In comparing means and standard deviations of L*, a*, and b* color values there was no significant difference by the manufacturing method and zirconia core thickness according to a two-way ANOVA. The color differences between two manufacturing methods were in a clinically acceptable range less than or equal to 3.7 in all the specimens. **CONCLUSION.** Based on the results of this study, a carefully consideration is necessary while selecting upper porcelain materials, even if it is performed on a small scale. However, because the color reproducibility of the digital veneering system was within the clinically acceptable range when comparing with conventional layering system, it was possible to estimate the possibility of successful aesthetic prostheses in the latest technology. ***[J Adv Prosthodont 2014;6:71-8]***

KEY WORDS: All ceramic restoration; Color reproducibility; Digital veneering; Spectrophotometer

INTRODUCTION

Dental technicians and dentists have made a sustained effort to create porcelain restorations that aesthetically match the patient's natural teeth. More than just the structural aesthetics, restoration of anterior teeth requires a dental prosthesis with the same shade compared to adjacent teeth. Dentists should transmit correct and objective information regarding color of the patient's natural teeth to dental technicians for a satisfactory dental prosthesis. Scientific understanding of color molding and collaborative dental care with dental technicians are critically needed so that the transmitted information can be accurately represented.[1]

In order to create natural-looking porcelain restorations, it is necessary to design elements such as opacity of the porcelain layer, shade and thickness such that they are in harmony with the patient's oral information. The elements determining the aesthetic outcome of restorations are the combination of the porcelain layers used, thickness, shade,

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and opacity. It also depends on the manufacturer of the porcelain powder, the batch, the frequency of porcelain firing and the condensation technique employed.[2-4] At the same time, the aesthetic outcome of each prosthesis is also based on the experience and skill of the dental technician. Sustained efforts and practice are required to reproduce the even shade and form of natural teeth, because most manufacturing processes depend on the manual dexterity of dental technicians.

Some materials used for early all-ceramic crowns were limited in clinical use, due to their weak properties. Therefore, the applicability of various materials was tried. Recently, zirconia-based all-ceramic crowns have begun to receive attention. Compared to the existing materials for all-ceramic crowns, zirconia has excellent flexural and fracture strength and abrasion resistance and biocompatibility.[5] However, questions have been raised about the clinical applicability of all-ceramic crowns with monolithic zirconia structure due to the time required to cut, the shrinkage after complete sintering, the opaque shade, and the wear of opposing teeth. Thus, in order to overcome these shortcomings and to create accurate, aesthetic prostheses that are more similar to natural teeth, it is necessary to build the porcelain layer on a core of zirconia.[6]

Currently, various techniques are being used for building up upper porcelain on zirconia cores,which include the Powder Slurry technique used for fabricating metal-ceramic crowns built up with porcelain powder and the Heat Pressing technique similar to the previously released IPS Empress system. The former has disadvantages because the restorations lack uniformity of shade and micro-bubbles can form during the lamination process, depending on the degree of skilled technique of the dental technicians. On the other hand, the latter has the advantage that it is possible to overcome the limitations of the former traditional build up method.[7]

Recently, the Digital Veneering System (Lava™ DVS, 3M ESPE, Seefeld, Germany), has been introduced to reduce the production time and produce more aesthetic prostheses. It combines the porcelain super-structure with a zirconia core, by using fusion powder after milling exclusive glass ceramic blocks through dental Computer-Aided Design/Computer-Aided Manufacture (CAD/CAM). The digital veneering system consists of 8 core colors, 10 fusion powders, and 4 glass ceramic blocks. Lava Fusion powder™ (3M ESPE, Seefeld, Germany) plays a role in fusing the upper porcelain crown made by milling ceramic blocks and zirconia core, and in representing the dentin color. The ceramic block serves as enamel.[8]

In order to produce aesthetic prostheses by using all-ceramic crowns, it is necessary to minimize the elements affecting porcelain shade. It is known that the porcelain shade is affected by factors such as thickness or volume of built up porcelain, degree of discoloration of abutments, shade guide, and shade selection process of dentists.[9] Dozić *et al.*[2] suggested that there was a significant correlation between the thickness of porcelain layered in the opaque and veneering porcelain system and that of the core. Douglas and Przybylska[10] reported that an increase in the thickness of opaque all-ceramic crowns could not achieve successful results of shade harmony. Heffernan *et al.*[11] found that core thickness and veneering porcelain had an effect on the overall transparency, and In-ceram® Empress® and Procera® were suitable for teeth with average brightness and transparency. However, insufficient research has been conducted on the effects of shade change in these studies, when differentiating the manufacturing method of upper porcelain, because they are limited to studies on shades of porcelain and core build up by manual lamination method.

The objectives of this study was to evaluate the clinical acceptability of all-ceramic crowns fabricated by the digital veneering method vis-à-vis the traditional method by examining the differences in shade according to the different build up methods using zirconia cores with three different thickness (0.3, 0.5, and 0.7 mm thickness).

MATERIALS AND METHODS

This study used Lava™ Frame (3M ESPE, Seefeld, Germany) partially sintered zirconia core. It also used Lava™ Ceram (3M ESPE, Seefeld, Germany) recommended by the manufacturer for manual porcelain build up after zirconia sintering in the Conventional Layering System group (CLS group). For porcelain build up by Digital Veneering System (DVS group), specimens were produced using Lava™ glass ceramic block (3M ESPE, Seefeld, Germany) and Lava™ Fusion powder (3M ESPE, Seefeld, Germany) (Table 1).

Each specimen was 0.3, 0.5, and 0.7 mm in thickness.

Table 1. All ceramic materials used in the experimental groups

Group	Veneering technique	Material	Type	Lot No.	Manufacturer
CLS	Conventional Layering System	Lava™ ceram	Feldspathic porcelain	Lot #182479	3M ESPE, Seefeld, Germany
DVS	Digital Veneering System	Lava™ glass ceramic block, fusion powder	Glass ceramic	Lot #365026	3M ESPE, Seefeld, Germany

This study produced expanded specimens based on the shrinkage rate indicated by the manufacturer using the shades of FS1, FS3, and FS4 in the 14-mm square specimen. The final sintering process was carried out by a dedicated furnace, Lava™ Furnace 200 (3M ESPE, Seefeld, Germany), as per the instructions of the manufacturer. The size and shape of the fully sintered zirconia specimen was adjusted by a 1,000-grit sandpaper (Buehler Ltd., IL, USA), and it was then dried after being washed in an ultrasonic cleaner for 10 minutes.

In order to build up the upper porcelain of uniform thickness and size in specimens of the CLS group, this study used a silicone mold. The silicone mold was made by duplicating the shape of the completed specimen (square-shaped, 14 mm in width and 1.5 mm thick) using dental stone. 0.3, 0.5, and 0.7 mm-thick zirconia cores were placed on the bottom of the silicone mold respectively when building up upper porcelain, then porcelain separating fluid (Magic separator, Noritake Dental Supply Co., Ltd, Miyoshi, Japan) was evenly applied to the corner or side of the silicone mold. The upper porcelain was built up according to the instructions of the manufacturer after the porcelain separating fluid was dried. Build up was manually performed by using Lava™ Ceram (3M ESPE, Seefeld, Germany), which was the dedicated veneering porcelain for the zirconia specimen. In light of the shrinkage of the porcelain, all specimens were passed through the sintering process twice. The thickness of all specimens was uniformly adjusted to 1.5 mm after the whole sintering processes.

As per the instructions of the manufacturer, for the DVS group, air abrasion with Rocatec™ soft (3M ESPE, Seefeld, Germany) at 2.8 atmospheres and a distance of about 10 mm was performed for approximately 20 seconds. In light of approximately 15% shrinkage, the each shades of E1, E2 and E4 Lava™ glass ceramic block (3M ESPE, Seefeld, Germany) was processed to a 14-mm square after sintering, and the each shades of No.3, No.4 and No.5 Lava™ Fusion powder (3M ESPE, Seefeld, Germany) was sintered respectively according to the manufacturer's directions. After the building up and fusing process, the thickness between the zirconia core and the glass ceramic block should be 0.2 mm. The thickness of the upper porcelain was produced differently depending on the core thickness. All specimens were uniformly adjusted to the thickness of maximum of 1.5 mm, using a digital caliper (CD-15CPX, Mitutoyo Corp, Tokyo, Japan) capable of measuring up to one hundredth of a millimeter (Table 2). The veneering porcelains were produced in accordance with the firing schedule of the manufacturer (Table 3), and the sintering process was performed by a skilled dental technician. This was in order to minimize discrepancies between specimens, so as to produce identical specimens. Seven specimens for each experimental group, a total of 126 specimens, were made on 18 experimental groups. The grouping was done according to the two types of building up methods of upper porcelain (CLS and DVS), the three types of shades (A1, A2, and A3.5) and the three different thicknesses of zirconia cores (0.3, 0.5, and 0.7 mm). The color was measured using a spectrophotometer for quantitative analysis of the shade. The spectrophotometer used in this study was CM-3600A (Minolta Co., Osaka, Japan). Color measurement was taken under illuminant D65 of the CIE standard. An integrating sphere 0-45 was used by two xenon lamp flicker photometry. It was measured at a viewing angle of 8º. Zero-point adjustment was performed using a ZERO (0) adjustment box, and a 4-mm thick target mask was

Table 2. Layering structure of the experimental groups

Group	Lava™ Frame (mm)	Lava™ Ceram MO (mm)	Lava™ Ceram (mm)	Lava™ fusion powder (mm)	Lava™ glass ceramic block (mm)	Total (mm)
CLS	0.30 ± 0.01	0.20 ± 0.01	1.00 ± 0.01			1.50 ± 0.01
	0.50 ± 0.01	0.20 ± 0.01	0.80 ± 0.01			1.50 ± 0.01
	0.70 ± 0.01	0.20 ± 0.01	0.60 ± 0.01			1.50 ± 0.01
DVS	0.30 ± 0.01			0.20 ± 0.01	1.00 ± 0.01	1.50 ± 0.01
	0.50 ± 0.01			0.20 ± 0.01	0.80 ± 0.01	1.50 ± 0.01
	0.70 ± 0.01			0.20 ± 0.01	0.60 ± 0.01	1.50 ± 0.01

Table 3. Firing schedules for veneering porcelains

Material	Start temperature	Drying time	Temperature increase	Final temperature	Holding time
Lava™ Ceram	450℃	6 min	45℃	810℃	1 min
Lava™ Fusion powder	500℃	4 min	10℃	770℃	1 min

adhered to the specimen after adjusting the standard white by using a standard white board (X = 91.31, Y = 93.14, Z = 109.22). The mean value was calculated by setting the frequency of measuring the value three times in different parts for each specimen. The measured values were analyzed using a software program, SpectraMagic™ NX (Minolta Co., Osaka, Japan). Tristimulus values x, y, and z were obtained, and CIE $L^*a^*b^*$ color space was calculated using a dedicated software after mathematical transformation.

The differences in shade according to the build-up methods were calculated by quantifying ΔE^*(mean color difference), with the use of color difference equations representing the distance from the measured values L^*, a^*, and b^* to the three-dimensional space of 2 colors. The formulas for calculating the ΔE^* values and the differences in shade are as follows:

$\Delta E^* = \{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\}^{1/2}$

$\Delta L^* = L_2 - L_1$; Value L^* of specimens in the CLS group - Value L^* of specimens in DVS group; Brightness of specimens

$\Delta a^* = a_2 - a_1$; Value a^* of specimens in CLS group - Value a^* of specimens in DVS group; Degree of red-green specimens (red chroma), +: red direction, -: green direction

$\Delta b^* = b_2 - b_1$; Value b^* of specimens in the CLS group - Value b^* of specimens in the DVS group; Degree of yellow-blue specimens (yellow chroma), +: yellow direction, -: blue direction

There have been many studies on the interpretation of ΔE^* values. O'Brien *et al.*[12] reported that the consistency of color is excellent if the ΔE^* value is less than or equal to 1, clinically acceptable if the ΔE^* value is less than or equal to 2, and clearly distinguishable with the naked eyes if the ΔE^* value is greater than or equal to 3.7.[13,14] However, it is said that the clinically acceptable color difference represents a broader range than that perceived in a strictly controlled environment, because there are various variables in the oral environment.[15] Therefore, the standard of clinically acceptable color difference (ΔE^*) was determined as 3.7, by reference to the existing research literature.

The measured results were analyzed with IBM SPSS Statistics 20.0 program (IBM Corp., Armonk, NY, USA) in order to verify the statistical significance. The color differences in the prosthesis shade, based on the zirconia core thickness and build up method of upper porcelains, were reported as mean and standard deviation. An analysis was performed using two-way ANOVA in order to examine color differences according to the type of specimen shade and zirconia core thickness, because the population of the target specimens was normally distributed. Tukey's honestly significant difference (HSD) test was used to compare the statistical differences between each group after verification. The type I error level was determined as 0.05.

RESULTS

Table 4 shows the mean and standard deviation of the calculated CIE L^*, a^* and b^* color-space values after measuring CLS and DVS groups using a spectrophotometer. Lightness index L^* showed similar results in both CLS and DVS groups while the specimen shade tended to be dark as it approached A3.5. L^* value tended to increase and gradually darken as the zirconia core became thicker and the upper porcelain became thinner in the CLS group; the lightness index tended to increase and darken as the zirconia core became thicker and the upper porcelain became thinner in the DVS group. Regardless of the upper porcelain type, L^* values were high in the specimen with a thick zirconia core. Moreover, when differing in the build up method of the upper porcelain in the experimental group with the same

Table 4. Means and standard deviations (SDs) of CIE L*, a*, and b* in each group

	Core thickness	A1			A2			A3.5		
		L*	a*	b*	L*	a*	b*	L*	a*	b*
CLS	0.3 mm	84.31	0.48	18.18	81.22	1.09	22.88	74.81	1.28	28.02
		(0.16)	(0.19)	(0.14)	(0.18)	(0.16)	(0.13)	(0.11)	(0.10)	(0.16)
	0.5 mm	85.57	0.35	17.04	82.28	0.89	22.04	77.45	1.13	27.26
		(0.13)	(0.10)	(0.12)	(0.11)	(0.14)	(0.15)	(0.15)	(0.13)	(0.17)
	0.7 mm	86.32	0.09	16.34	83.75	0.62	20.80	79.97	0.88	26.26
		(0.11)	(0.12)	(0.13)	(0.18)	(0.17)	(0.16)	(0.12)	(0.13)	(0.19)
DVS	0.3 mm	83.25	-0.02	16.52	80.14	0.48	20.82	74.99	0.76	28.14
		(0.08)	(0.13)	(0.11)	(0.07)	(0.07)	(0.03)	(0.04)	(0.04)	(0.08)
	0.5 mm	84.44	-0.36	16.12	81.43	-0.02	19.34	76.92	0.36	27.71
		(0.10)	(0.08)	(0.10)	(0.10)	(0.12)	(0.07)	(0.15)	(0.08)	(0.04)
	0.7 mm	85.89	-0.52	15.68	82.79	-0.34	19.10	78.13	0.12	26.86
		(0.09)	(0.07)	(0.06)	(0.14)	(0.08)	(0.08)	(0.10)	(0.10)	(0.07)

shade, the CLS group showed darker L* values and darker shades than the DVS group. Saturation indexes a* and b* showed a similar tendency in both CLS and DVS groups as the specimen shade approached A3.5. a* value had a tendency to be reduced as the zirconia core became thicker and the upper porcelain became thinner, and decrease as the zirconia core became thicker, regardless of the effect of the upper porcelain type. When differing in the type of the upper porcelain in the experimental group with the same shade, the CLS group tended to be redder than the DVS group. Saturation index b* also tended to reduce as the zirconia core became thicker and the upper porcelain became thinner in both the CLS and DVS groups, and decrease as the zirconia core became thicker, regardless of the effect of the upper porcelain type. In addition, when differing in the buildup method of the upper porcelain in the experimental group with the same shade, the CLS group tended to be yellower than the DVS group (Fig. 1, Fig. 2, and Fig. 3).

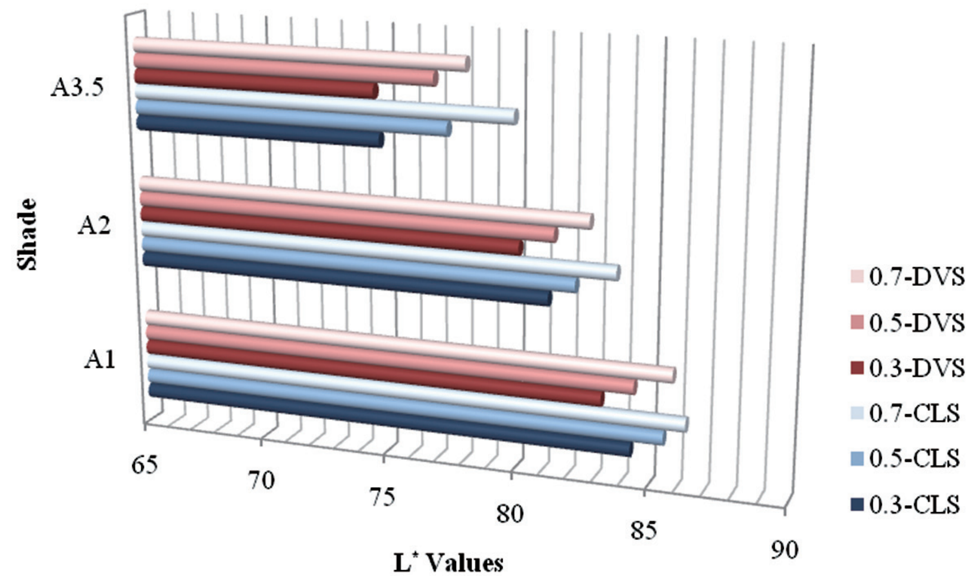

Fig. 1. Means of L* according to three types of core thickness and two types of veneering porcelain.

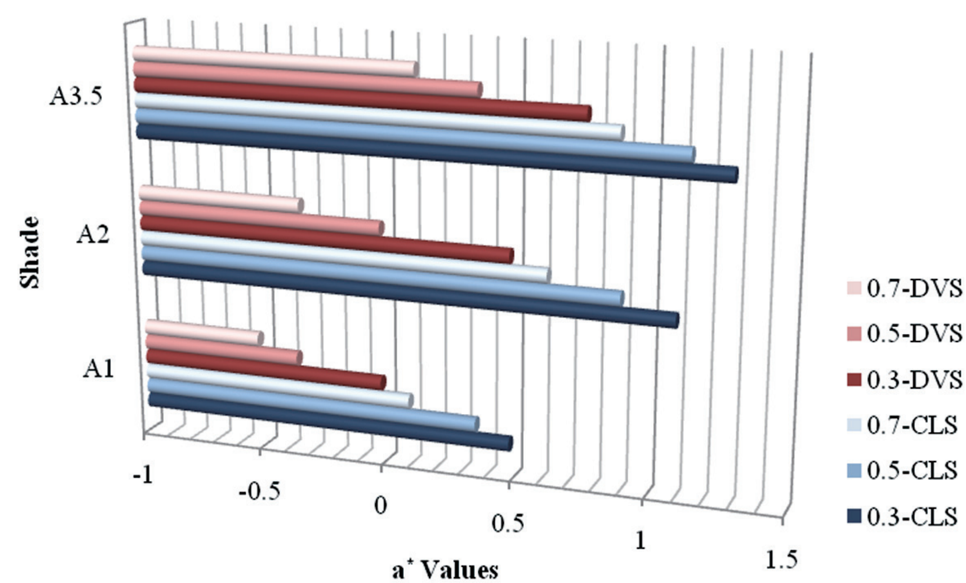

Fig. 2. Means of a* according to three types of core thickness and two types of veneering porcelain.

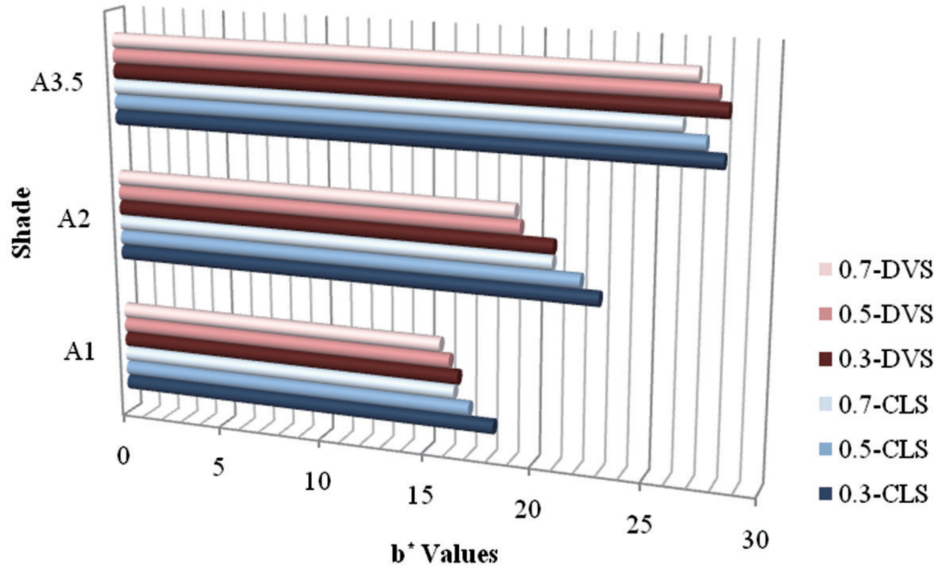

Fig. 3. Means of b* according to three types of core thickness and two types of veneering porcelain.

Table 5. Analysis of mean color difference (ΔE*) value by two types of veneering porcelain

	Mean ΔE (SD)*		
	0.3 mm	0.5 mm	0.7 mm
A1	1.72 (0.58)[Aa#]	1.54 (0.25)[Ab]	1.12 (0.74)[Ac]
A2	1.32 (0.47)[Aa]	1.11 (0.57)[Ab]	1.03 (1.21)[Ac]
A3.5	2.61 (1.03)[Aa]	2.21 (1.18)[Ab]	2.44 (0.96)[Ab]

* Means and standard deviations in parentheses.
[#] Data with the different letters are significantly different at 0.05 significance level. Upper cases mean the comparison in the types of veneering porcelain shade and lower cases mean the comparison in the types of zirconia core thickness.

The mean color difference was calculated using different upper porcelains as a variable in specimens with the same shade. The study examined the effect of upper porcelain shade and zirconia core thickness on the differences in color differences comparing means and standard deviations. It was found that there was a significant difference in shade according to the zirconia core thickness, while no significant difference in shade was found according to the upper porcelain. A two-way ANOVA model using the main effect of upper porcelain shade and zirconia core thickness explained 23.6% of the variation in shade differences. In a post-hoc analysis by multiple comparison analysis, there was no significant difference in color differences in relation to the upper porcelain shade, in specimens of A3.5 shade, with a zirconia core of 0.5 mm and 0.7 mm thickness. Regardless of the zirconia core thickness, the clinically acceptable values were found to be less than or equal to 3.7 in the shade of all specimens (Table 5).

DISCUSSION

Tooth color varies depending on tooth enamel, dentin, and structure and thickness of pulp in every individual. Many efforts have been made to reproduce the shape and other biological characteristics that are similar to natural teeth, as there has been an increasing demand for aesthetics recently. However, there are still many unresolved problems in representing optical phenomena, including the color of natural teeth, in dental porcelains.[16] It is quite difficult to define the shade of natural teeth and to represent various specific colors, because they even vary in the same tooth. It has been reported that the optical properties of dental porcelains used for prostheses are important; in porcelain restorations with a ceramic core, shade and transparency become primary elements for providing restorations with aesthetics, and major considerations in the selection of materials.[17] Appearance, surface, shape, translucency, and shade can be considered as elements affecting the aesthetics of porcelain restorations. There are limitations to producing restorations in which these elements are harmonized with natural teeth, because there is a difference in the light reflection and absorption properties of restorations vis-à-vis natural teeth. Although dental porcelains have been frequently used since they were clinically introduced in the 1970s due to their excellent properties of abrasion resistance, biocompatibility, and color reproduction, poorly-trained dental technicians cannot reproduce the various complex colors of natural teeth in good harmony due to the limitations of porcelain powder. At present, reproduction of natural tooth color depends on the experience and manual skills of dental technicians.[18]

Therefore, recently, there has been increasing interest in the Heat-press technique and the Digital Veneering System, as they compensate for the disadvantages of the Powder Slurry technique. The DVS processes both the zirconia core and the veneering porcelain together with the use of CAD/CAM, and holds it together with the use of fusion power. It can be said that this system can produce consistently high-quality prostheses with minimal human resources.[19] In this experiment, all specimens showed clinically acceptable values. Color differences exist regardless of the same shade of the restorations, because there are differences in crystal size and transparency between the upper porcelain materials, mostly consisting of glass-ceramic for the DVS group and feldspathic porcelains for the Powder Slurry technique (CLS group). Therefore, shade differences existed even though the same shade was clearly specified.

This study compared the color reproducibility of Digital Veneering System (DVS) with a traditional build-up method of upper porcelain (CLS) when making aesthetic prostheses based on zirconia core. In this experiment, color of the specimens was measured under examining Standard Illuminant D65 using a spectrophotometer, and the CIE L^*, a^*, b^* color space was used for quantitative evaluation of shades. The CIE L^*, a^*, b^* color space was specified by the International Commission of Illumination in 1976 and is most commonly used in all fields currently. Seghi *et al.*[3] reported that the CIE-Lab color space provided objective criteria when measuring the color of dental porcelains. Therefore, the L^*, a^* b^* values were measured to evaluate ΔE^*, and then, it was defined as a criterion of the color reproducibility.

Concurring with the results in this paper, based on the actual clinical situation, it has been reported recently that 50% of dentists perceive color differences when the ΔE_{ab} value is 2.6, and 50% of dentists request to reproduce restorations due to the color mismatch.[15] Therefore, it will be possible to highly appreciate the clinical benefits, when comparing the DVS group with the CLS group, in this experiment.

This study observed the color differences in relation to the zirconia core thickness and build up method of upper porcelain in all specimens with the same shade. As a result, there were significant differences in the color differences as the zirconia core became thicker and the upper porcelain became thinner (P<.05). In addition, the color differences in relation to the core thickness showed a tendency to decrease slightly as the specimen shade became darker. These are similar to the results of the study by Luo and Zhang[20] on all-ceramic porcelain shades, and coincides with the results of the study by Lee *et al.*[21] on the effect of core thickness and type of upper porcelain on the restoration shade.

It can be considered that the color reproducibility of A3.5 group varied greatly from other groups (A1 and A2) in this experiment because the color instability had an effect on the porcelain shade after sintering metal oxides color additives for the porcelain.[22] In addition, Douglas and Przybylska[10] reported that shade differences for each specimen (A1, A2, and A3.5) were most affected by the L^* value. Therefore, the shade differences become smaller as the brightness becomes higher and shade becomes brighter.

In this study, the final shade of porcelain restorations was determined by the proportion of core thickness and upper porcelain. In light of the recent trends that emphasize on aesthetics regardless of the degree, it is suggested that it is possible to produce clinically satisfactory restorations only by careful selection of materials, even if it is performed on a small scale. Moreover, it will be necessary to objectively evaluate the glass ceramic blocks used for upper porcelains and the shade of fusion powder, in order to produce aesthetic restorations using the digital veneering system. If various subsequent studies focus not only on the porcelain shade, but also the transparency, it will be useful in extending the clinical application.

CONCLUSION

The color difference (ΔE^*) value was considered to be a clinically acceptable value, if less than or equal to 3.7. Based on the above results, it can be inferred that all-ceramic crowns using zirconia by different manufacturing methods and materials of upper porcelain, may show more or less color differences in a clinically acceptable range even when the materials used have the same shade. It may be concluded that he digital veneering system is a clinically acceptable method of producing aesthetic prostheses, the color variance was within the clinically acceptable range. It is considered that this study can help to extend clinical applications of digital veneering system. In consideration of these characteristics when clinically using it, it will necessary to select and use an appropriate system for patients' oral environment.

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