Effect of ceramic material and resin cement systems on the color stability of laminate veneers after accelerated aging

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ABSTRACT

Statement of problem. Laminate veneers are susceptible to color change during clinical service. Studies that compare the effects of different ceramic and resin cement systems on color stability are lacking.

Purpose. The purpose of this in vitro study was to evaluate the color stability of laminate veneers after accelerated aging using different ceramic and resin cement systems.

Material and methods. Ceramic specimens (N=168; shade A1; thickness, 0.50 ±0.05 mm; diameter, 10.00 ±0.10 mm) were prepared using nanofluorapatite and lithium disilicate (high translucency [HT] to low translucency [LT]) ceramics. Light-polymerizing (LP) cements were classified by brightness (high or low). Dual-polymerizing cements were classified by composition (base-only [DB] or base-catalyst [DC]) for comparison of color stability on the basis of polymerization type. DB cement was light-polymerizing, whereas DC cement was dual-polymerizing. They were further classified by shade (transparent, white, or yellow [n=7, each]). Color difference (ΔE) values were obtained by spectrophotometric quantification of L* (lightness), a* (green-red), and b* (blue-yellow) values before and after aging. The Kruskal-Wallis, Mann-Whitney *U*, Wilcoxon signed rank, and Bonferroni post hoc tests were used for statistical analysis.

Results. After specimens were subjected to accelerated aging, HT ceramic specimens luted with yellow-shade DC cement exhibited the greatest color change (ΔE=2.11), whereas HT and LT ceramic specimens luted with low-brightness LP cement exhibited the least color change (ΔE=1.37). In HT ceramic specimens, which exhibited the greatest color change of the 3 ceramic types, transparent shade cement exhibited significantly lower ΔE values than the other shades with DB ($P<.001$) and DC cements ($P=.010$). High-brightness cement exhibited significantly higher ΔE values than low-brightness cement when used with NF ($P=.017$), HT ($P<.001$), and LT ($P<.001$) ceramics. The ΔE values of DB cement were not always lower than those of DC cement. For all specimens, the aging of laminate veneers decreased the L* values and increased the a* and b* values.

Conclusions. Ceramic and resin-cement systems affected the color stability of laminate veneers. Relative to other ceramics, HT lithium disilicate ceramics exhibited greater color changes upon aging. For HT ceramics, the use of transparent shade resin cement is recommended. The lower the brightness of resin cement, the higher the color stability of veneers. For luting of 0.5-mm-thick laminate veneers with dual-polymerizing cement, light polymerization did not yield better color stability than dual polymerization over time. (J Prosthet Dent 2018;120:99-106)

With improvements in dental ceramics and resin cements, various treatment options have become available for anterior teeth, and interest in esthetic restoration is increasing.[1] Laminate veneers provide high-quality esthetics and good clinical results.[2,3] To achieve good esthetics, color harmony between the laminate veneer and adjacent teeth is essential. Long-term color stability is essential to achieve long-term success with laminate veneers. Factors that affect their esthetics include the ceramic fabrication technique, material,[4,5] thickness of the ceramic,[6,7] shade of the resin cement, and polymerization method.[8,9] Additionally, the use of evaluation paste can predict the outcome after cementation.[10] Thus, patients and practitioners can expect a natural appearance after definitive cementation.

The high translucency of laminate veneers confers natural tooth appearance through the lens effect.[11] However, its low masking ability is a disadvantage, which means that discoloration can be visible through the ceramic.[12,13] Since the laminate veneer is thin, the properties of the resin cement dictate the final color of veneers.[8,14] Various shades[14,15] and brightness levels[16,17] of resin cements affect the color

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Clinical Implications

Ceramic material and resin-cement systems affect the color stability of laminate veneers after accelerated aging. Careful consideration of shade, brightness, and polymerization type is necessary in the selection of resin cements for laminate veneers.

stability of veneers differently. In addition, the effect of polymerization type on color stability needs further investigation.[18-20] In dual polymerization, the aromatic tertiary amine, which reacts with the benzoyl peroxide initiator in the catalyst, causes discoloration during polymerization.[21-23] In light polymerization, discoloration is caused by initiation of the camphorquinone (CQ)/aliphatic amine complex.[24,25]

Accelerated aging systems have been used to evaluate the color stability of dental materials, including that of dental ceramics and resin cements.[26-29] These systems simulate clinical conditions by exposing the materials to ultraviolet light, heat, continuous humidity, and variations in temperature to accelerate their degradation. Studies by Bagis and Turgut[4] and Turgut and Bagis[30] found that an aging cycle of 150 kJ/m^2 is equivalent to a year of exposure to clinical conditions.

Several studies have investigated color changes in laminate veneers after aging. Almeida et al[9] reported low color stability with dual polymerization, while Turgut and Bagis[30] reported no significant difference in color stability according to polymerization type over long-term observation. However, these studies usually used only 1 type of ceramic or cement; therefore, the applicability of their results is limited. Moreover, some studies used ceramic crowns and not laminate veneers. Studies of the effect of the aging process on long-term stability are lacking. Therefore, the present study focused on evaluating the color stability of laminate veneers through aging by using various ceramic and resin cement systems. Color stability was evaluated according to the ceramic system, shade and brightness of resin cement, and polymerization type. The specimens were quantitatively analyzed for changes in color after aging.

The 3 null hypotheses were that the type of ceramic system would not affect the color stability of laminate veneers; that color changes in laminate veneers would not be affected by the shade or brightness of resin cement; and that, with dual-polymerizing cement, light polymerization would provide better color stability than dual polymerization.

MATERIAL AND METHODS

A total of 168 disk-shaped specimens of shade A1 were prepared using 3 different ceramics — nanofluorapatite

Table 1. Ceramic systems used

Ceramic System	Material*	Shade
Nanofluorapatite	IPS e.max Ceram	A1
High translucency lithium disilicate	IPS e.max press HT	A1
Low translucency lithium disilicate	IPS e.max press LT	A1

*Products of Ivoclar Vivadent AG.

(NF [e.max Ceram; Ivoclar Vivadent AG]) and lithium disilicate (HT [e.max Press HT] and LT [e.max Press LT]; high to low translucency; Ivoclar Vivadent AG) (Table 1). All specimens were prepared according to the manufacturer's instructions. To compensate for ceramic shrinkage and distortion, the specimens were made slightly larger than the desired size. The NF ceramic was prepared by mixing ceramic powder with distilled water in a polytetrafluoroethylene (PTFE [Teflon]) mold (thickness, 1.0 mm; diameter, 16.0 mm). These specimens were then fired at 770°C, in accordance with the manufacturer's instructions (IPS Programat EP 5000; Ivoclar Vivadent AG). The HT and LT ceramic specimens were prepared using a waxing process in a PTFE mold (thickness, 0.8 mm; diameter, 11.0 mm). They were then invested and heat-pressed in the same furnace as the NF specimens. The specimens were machine ground (HRG-150; AM Technology) and polished on 1 side using a grinding machine (SPL-15 Grind X; Okamoto) with a 6-μm diamond slurry and then a 1-μm grit size to ensure a uniform thickness of 0.50 ±0.05 mm and diameter of 10.00 ±0.10 mm. The dimensions were verified using digital calipers (Absolute 500; Mitutoyo Co). Seven specimens were prepared per group. Each specimen was autoglazed and then ultrasonically cleaned with distilled water for 10 minutes.

Table 2 presents the resin cement systems used in this study. Light-polymerizing cements (LP [Variolink veneer; Ivoclar Vivadent AG]) were classified based on brightness as high- or low-brightness cements. Dual-polymerizing cements (Variolink N; Ivoclar Vivadent AG) were classified based on composition as base-only (DB) or base-catalyst (DC) cements for comparison of color stability according to polymerization type. DB cement was light-polymerized, while DC cement was dual-polymerized. These cement systems were further classified based on shade as transparent, white, or yellow. Thus, the total number of test groups in this study was 24.

According to International Organization for Standardization standard 7491 (Dental materials—Determination of color stability), the background should be durable and white.[31] It should also be color stable to allow the evaluation of color change in ceramics and resin cements. Therefore, an acetal polyoxymethylene material (Delrin White; DuPont) with proven durability and color stability was used for the background.[32] In a pilot study to determine whether the background material met the requirements, the Delrin White background was subjected to aging, upon which the material was

Table 2. Resin cement systems used

Resin Cement	Polymerizing Type	Shade	Monomer Matrix
Light-polymerizing only (Variolink Veneer)[a]	Light-polymerizing	High brightness Low brightness	Dimethacrylate
Dual-polymerizing; Base only (Variolink N)[a,b]	Light-polymerizing	Transparent White Yellow	Bis-GMA, UDMA, TEGDMA
Dual-polymerizing; Base and Catalyst (Variolink N)[a,b]	Dual-polymerizing	Transparent White Yellow	Bis-GMA, UDMA, TEGDMA, Benzoyl peroxide

Bis-GMA, bisphenol-A glycidyl dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate. [a]Products of Ivoclar Vivadent AG. [b]in Asia; same product marketed as Variolink II in the United States.

Figure 1. Schematic of specimen cementation by using stainless steel jig for 0.1-mm cement thickness.

confirmed to be color stable (color difference [ΔE] value of <1). The size of the acetal background was set at 2.4 mm thick × 48.0 mm high × 68.0 mm wide to ensure that it fit in the holder of the aging machine. To increase the surface roughness and, thus, the bond strength of the resin, abrasive papers of increasing grit size (800, 1200, and 2000) were used consecutively to finish the material. Debris was removed by ultrasonic cleaning for 10 minutes, after which 37% phosphoric acid was applied for 30 seconds. The material was then washed and air dried. A bonding agent (ExciTE F DSC; Ivoclar Vivadent AG) was then applied and air dried.

The surface was etched with hydrofluoric acid (IPS ceramic etching gel; Ivoclar Vivadent AG) for 60 seconds for NF ceramic or for 20 seconds for HT and LT ceramics. The ceramics were rinsed and air dried. A ceramic primer (Monobond S; Ivoclar Vivadent AG) was applied for 60 seconds and then air dried. After application of the bonding agent, the specimens were cemented with resin cements. Light-polymerizing cement was directly applied to the unglazed surface of the ceramic, while the dual-polymerizing cement was mixed on a separate mixing pad with a plastic spatula before application. A clean glass-slide was placed on top of a 0.6-mm-thick stainless steel jig and pressed with a 9.8-N load for 20 seconds to attain a uniform cement thickness of 0.1 mm (Fig. 1).[3,30,33] The cement was light polymerized through the ceramic surface for 40 seconds using a light-emitting diode polymerization unit (Demi; Kerr Corp), after which the excess cement was removed. Ceramic and cement thicknesses after cementation were verified using digital calipers. All specimens were stored for 24 hours in a 37°C water bath (JSR JSSB-50T; JS Research).

After cementation, color measurements were recorded using a spectrophotometer (Color eye 7000-a; Gretag Macbeth LLC); this device has been successfully used to measure the color of dental ceramics with reproducible results.[14,32] The device was calibrated by using a white calibration tile and a light trap. Measurements were recorded under D65 standard illumination with ultravi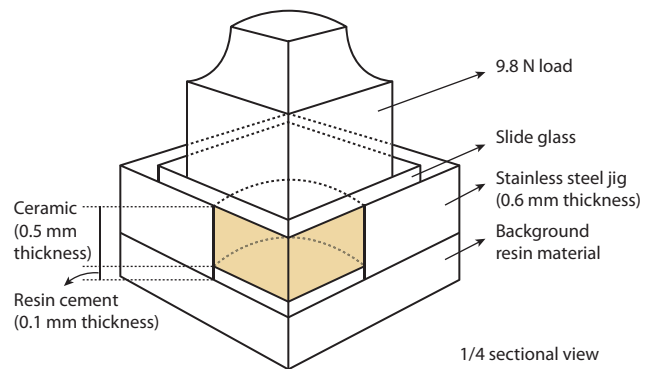olet light and specular component included with an optical geometric configuration of 8 degrees. Color measurements were defined using Commission Internationale De L'éclairage (CIE) color system, which defines L*, a*, and b* values for specimens, where L* is the brightness ranging from 0% to 100%, and a* and b* are chromaticity variables. The field of view was positioned on the center of each specimen, and the L*a*b* color values were consecutively measured 3 times. The average of the readings was calculated to obtain the initial color of the specimen. Data were analyzed using software (Color iQC basic v8.4.3; X-Rite Inc).

After the first color measurement, all specimens were subjected to aging using the Weather-o-Metre machine (Atlas ci 4000; Atlas Electronic Devices Co). A xenon light (0.55 W/m^2/nm) filtered through 340-nm borate borosilicate glass was used as the light source. The aging process was as follows: 60 minutes in the dark with back water spray; 40 minutes under illumination; 20 minutes under illumination water spray; and 60 minutes under illumination. The temperature of the back panel was maintained at 38 ±2°C in the dark and 70 ±3°C under illumination. The dry-bulb temperature was 38 ±2°C in the dark and 47 ±3°C under illumination. Relative humidity was maintained at 95 ±5% in the dark and 50 ±5% under illumination. A total radiant energy of 150 kJ/m^2 was applied. After the first aging process, the specimens were subjected to a second aging, resulting in a total applied energy of 300 kJ/m^2. After specimens were aged, color measurements were recorded again under the same conditions. The L*, a*, and b* values of each specimen before and after aging were compared to obtain the CIE color differences (ΔE) according to the equation: $\Delta E=([L_1{}^* - L_2{}^*]^2 + [a_1{}^* - a_2{}^*]^2 + [b_1{}^* - b_2{}^*])^{1/2}$.

The ΔE values were analyzed in accordance with clinical color-matching tolerance criteria, which allow clinicians to interpret color differences with the aid of detailed descriptions (0, perfect; 0.5 to 1, excellent; 1 to 2, good; 2 to 3.5, clinically acceptable; and >3.5, mismatch).[34-36] Thus, ΔE values >3.5 were considered clinically unacceptable.

Table 3. Color values of specimens for NF ceramic

Resin Cement	Shade	First Aging				Second Aging			
		ΔE	SD	P	1-β	ΔE	SD	P	1-β
Light-polymerizing only	High brightness	1.24	0.13	.026	.661	1.66	0.17	.017	.764
	Low brightness	1.08	0.11			1.45	0.11		
Dual-polymerizing; base only	Transparent	1.07	0.13	.750	.100	1.54	0.11	.340	.227
	White	1.15	0.14			1.57	0.15		
	Yellow	1.12	0.10			1.67	0.17		
Dual-polymerizing; base and catalyst	Transparent	1.26	0.23	.510	.163	1.65	0.36	.642	.091
	White	1.14	0.23			1.65	0.29		
	Yellow	1.21	0.11			1.91	0.55		

1-β, power; ΔE, color difference; NF, nanofluorapatite ceramic; SD, standard deviation.

Since the number of specimens in each group was 7, data were analyzed using a nonparametric test. The Kruskal-Wallis test was used to compare the ΔE values of ceramics and resin cement shades. The Mann-Whitney U test was used to compare ΔE values as functions of the polymerization type and brightness of resin cement. Changes in L*, a*, and b* values after aging were compared by using the Wilcoxon signed-rank test. The Bonferroni method was used for post hoc analysis. The ΔE and L*, a*, and b* values of the specimens were analyzed by using statistical software (SPSS Statistics v17.0; SPSS Inc) (α=.05).

RESULTS

Tables 3 to 5 present the mean ΔE values after aging for all experimental groups. Of all groups, HT ceramics luted with yellow-shade DC cement exhibited the greatest color change (ΔE=2.11), whereas HT and LT ceramics luted with low-brightness LP cement exhibited the least color change (ΔE=1.37).

The ΔE values of different ceramic systems are presented in Figures 2 and 3. The post hoc test results are presented in Supplemental Tables 1 and 2. High translucency ceramics exhibited the greatest color change. Relative to the other ceramics, HT ceramics exhibited significantly higher ΔE values, particularly when luted with high brightness (P<.001) and white shade (either light [P<.001] or dual polymerization [P=.024]) cements. No significant color differences were found between NF and LT ceramics in any of the groups, except when luted with yellow shade DC cement after first aging (P=.038).

Figure 4 presents ΔE values according to the shade of resin cement, and the post hoc test results are presented in Supplemental Tables 3 and 4. No significant differences were found in ΔE values among different shades of cement in the case of NF ceramics luted with DB (P=.340) or DC (P=.642) cement and LT ceramics luted with DB cement (P=.208). However, in HT ceramics, transparent shade cement exhibited significantly lower ΔE values

Table 4. Color values of specimens for HT ceramic

Resin Cement	Shade	First Aging				Second Aging			
		ΔE	SD	P	1-β	ΔE	SD	P	1-β
Light-polymerizing only	High brightness	1.57	0.10	<.001	.999	2.08	0.08	<.001	.999
	Low brightness	1.10	0.06			1.37	0.09		
Dual-polymerizing; base only	Transparent	1.26	0.13	.007	.933	1.57	0.19	<.001	.998
	White	1.47	0.10			1.96	0.12		
	Yellow	1.27	0.08			1.75	0.11		
Dual-polymerizing; base and catalyst	Transparent	1.39	0.15	.010	.870	1.78	0.16	.010	.937
	White	1.48	0.15			1.95	0.18		
	Yellow	1.63	0.11			2.11	0.15		

1-β, power; ΔE, color difference; HT, high translucency lithium disilicate ceramic; SD, standard deviation.

Table 5. Color values of specimens for LT ceramic

Resin Cement	Shade	First Aging				Second Aging			
		ΔE	SD	P	1-β	ΔE	SD	P	1-β
Light-polymerizing only	High brightness	1.35	0.07	<.001	.999	1.72	0.10	<.001	.999
	Low brightness	1.02	0.10			1.37	0.10		
Dual-polymerizing; base only	Transparent	1.11	0.16	.387	.186	1.56	0.18	.208	.322
	White	1.02	0.11			1.50	0.12		
	Yellow	1.10	0.12			1.62	0.12		
Dual-polymerizing; base and catalyst	Transparent	1.27	0.11	.080	.498	1.65	0.15	.044	.642
	White	1.19	0.11			1.57	0.14		
	Yellow	1.49	0.30			2.06	0.43		

1-β, power; ΔE, color difference; LT, low translucency lithium disilicate ceramic; SD, standard deviation.

than the other shades with both DB (P<.001) and DC (P=.010) cement.

Figure 5 presents ΔE values as functions of brightness of resin cement. The Mann-Whitney U test results are presented in Supplemental Tables 5 and 6. High brightness resin cements exhibited significantly higher ΔE values than low brightness cements in NF (P=.017), HT (P<.001), and LT (P<.001) ceramics.

Figures 6 and 7 present ΔE values as functions of the polymerization type of resin cement. The Mann-Whitney U test results are presented in Supplemental Tables 7 and 8. As shown in Figure 7, only 2 ceramic groups, HT and LT, luted with yellow shaded cement, showed significant differences in ΔE values after second aging based on polymerization type. In LT ceramics, DC cement exhibited lower color stability after first aging than did DB cement, regardless of cement shade; however, over time, no significant differences were observed between the 2 groups in specimens of transparent (P=.456) or white (P=.209) shade. In NF ceramics, no differences were found in ΔE values according to polymerization type in specimens of transparent (P=.535), white (P=.535), or yellow (P=.259) shade.
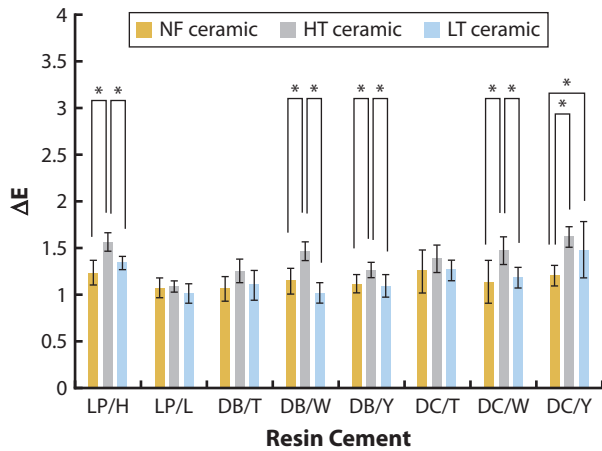
Figure 2. Color difference (ΔE) values of ceramic systems after first aging. *Significant difference at *P*<.05. Error bars represent standard deviations. DB, base use in dual-polymerizing cement; DC, base catalyst use in dual-polymerizing cement; H, high-brightness; HT, high translucency lithium disilicate ceramic; L, low-brightness; LP, light-polymerizing cement; LT, low translucency lithium disilicate ceramic; NF, nanofluorapatite ceramic; T, transparent shade; W, white shade; Y, yellow shade.

Figure 3. Color difference (ΔE) values of ceramic systems after second aging. *Significant difference at *P*<.05. Error bars represent standard deviations. DB, base use in dual-polymerizing cement; DC, base catalyst use in dual-polymerizing cement; H, high-brightness; HT, high translucency lithium disilicate ceramic; L, low-brightness; LP, light-polymerizing cement; LT, low translucency lithium disilicate ceramic; NF, nanofluorapatite ceramic; T, transparent shade; W, white shade; Y, yellow shade.

Figure 8 presents the changes in CIE L*, a*, and b* values after aging. Results of the Wilcoxon signed rank test revealed a decrease in L* values and increases in a* and b* values in all groups. The b* values exhibited the greatest change in all groups, except in HT ceramics luted with high-brightness cement.

DISCUSSION

In the present study, the color stability of laminate veneers was affected by differences in ceramic materials and resin cement systems. The first null hypothesis, that the ceramic system would not affect the color stability of laminate veneers, was rejected. Except in specimens luted with low brightness LP cement, HT ceramics exhibited the greatest color change among the 3 ceramic systems. Ledić et al[12] and Vichi et al[13] reported that HT ceramics exhibited higher translucency than NF and LT ceramics of the same shade. Therefore, ceramics of higher translucency are thought to be less able to mask discoloration of the resin cement than ceramics of lower translucency. In the present study, HT ceramics exhibited statistically significant color changes particularly when luted with high-brightness LP cement and white shade DB or DC cement. If the above-described combinations are used for cementation, careful bonding procedures, and adequate polymerization time are deemed necessary for optimal results.

The second hypothesis, that color change in laminate veneers would not be affected by the shade or brightness of resin cement, was rejected. In HT ceramics, cements of transparent shade exhibited significantly lower color changes than those of other shades. In a clinical
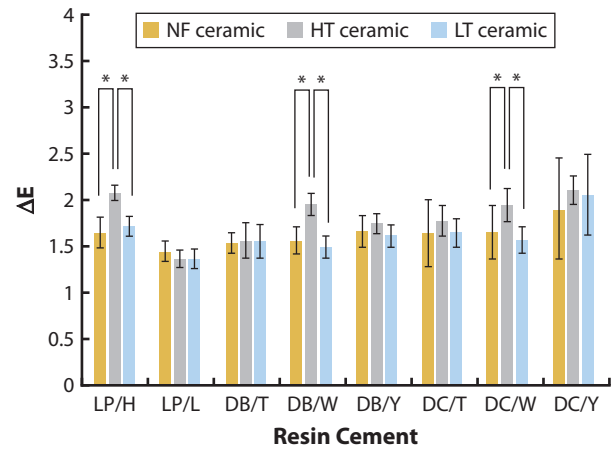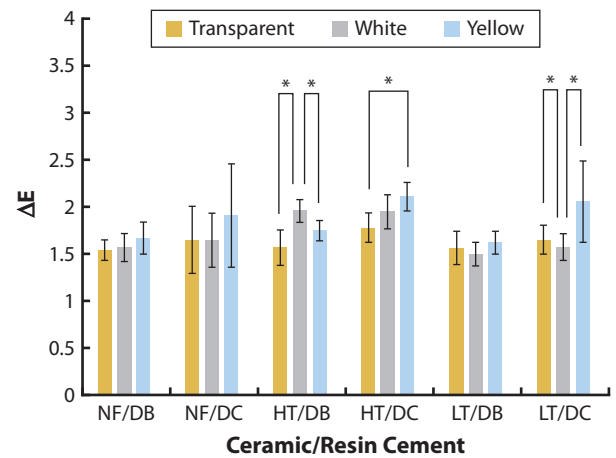

Figure 4. Color difference (ΔE) values according to shade of resin cement after second aging. *Significant difference at *P*<.05. Error bars represent standard deviations. DB, base use in dual-polymerizing cement; DC, base catalyst use in dual-polymerizing cement; HT, high translucency lithium disilicate ceramic; LT, low translucency lithium disilicate ceramic; NF, nanofluorapatite ceramic.

situation, if discoloration of the abutment is not significant, staining of HT ceramics is recommended to achieve a natural appearance. Application of white or yellow shade cements inside a ceramic veneer (with shade effects) could result in the stained ceramic having a different color.[11] Therefore, transparent shade cements are recommended for HT ceramics in clinical situations. The effect of shade variation on the color stability of veneers may be influenced by various interactive factors owing to diversity in ceramic materials and products.[17] These effects should be evaluated by further research.
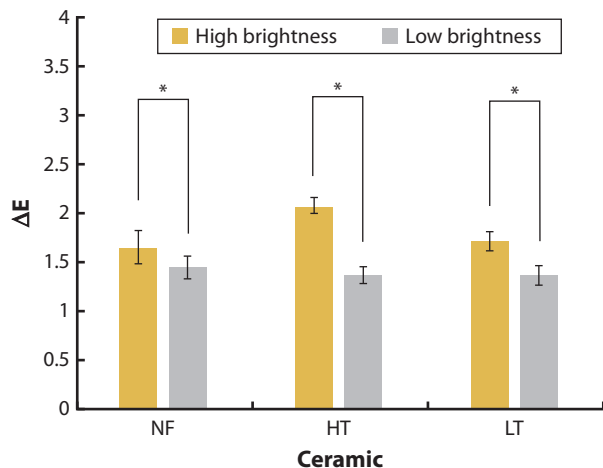
Figure 5. Color difference (ΔE) values as functions of brightness of resin cement after second aging. *Significant difference at $P<.05$. Error bars represent standard deviations. HT, high translucency lithium disilicate ceramic; LT, low translucency lithium disilicate ceramic; NF, nanofluorapatite ceramic.

Figure 6. Color difference (ΔE) values as functions of polymerizing type of resin cement after first aging. *Significant difference at $P<.05$. Error bars represent standard deviations. HT, high translucency lithium disilicate ceramic; LT, low translucency lithium disilicate ceramic; NF, nanofluorapatite ceramic; T, transparent shade; W, white shade; Y, yellow shade.

In addition, low-brightness LP cement exhibited lower ΔE values than high-brightness LP cement. Pissaia et al[16] and Uchida et al[17] reported a relatively high tendency for discoloration in lighter shades of resin cement because of polymer degradation. This leads to the release of monomers and causes the color of the polymerized resin to shift to that of the monomers, resulting in more visible change.

The third hypothesis, that in dual-polymerizing cement, light polymerization would provide greater color stability than dual polymerization, was rejected. Except for 2 groups, none of the test groups exhibited significant differences in color change according to polymerization type. In dual polymerization, the formation of oxidative products of yellowing compounds by oxidation of excess amines is thought to be the main cause of discoloration; however, CQ/aliphatic amine complex photoinitiation in light polymerization can also cause discoloration.[21-24] To overcome the discoloration issue associated with dual polymerization, Oei et al[25] reported new color-stable initiators which provide color outcomes comparable with those of light polymerization. In addition, instead of the conventional amine, a colorless co-initiator (*p*-octyloxyphenyl-phenyl iodonium hexafluoroantimonate) can be added to improve the color stability and degree of polymerization.[19]

In resin cements, a low degree of polymer conversion could explain discoloration.[21–23] First, acidic monomers remaining on the tooth surface after etching can react with amines to inhibit the redox reaction of the resin. This adverse reaction depends on acidity. Therefore, before the application of resin cement, the presence of residual acidic monomers should be minimized. Bonding agents such as ExciTE F DSC have sulfonic acid sodium salt components which react
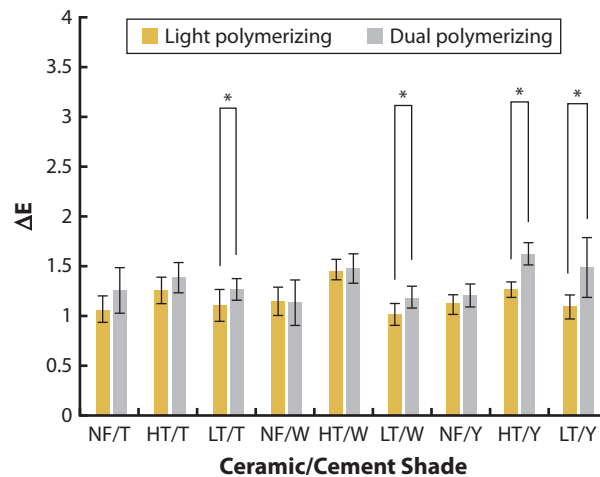

Figure 7. Color difference (ΔE) values as functions of polymerizing type of resin cement after second aging. *Significant difference at $P<.05$. Error bars represent standard deviations. HT, high translucency lithium disilicate ceramic; LT, low translucency lithium disilicate ceramic; NF, nanofluorapatite ceramic; T, transparent shade, W, white shade; Y, yellow shade.
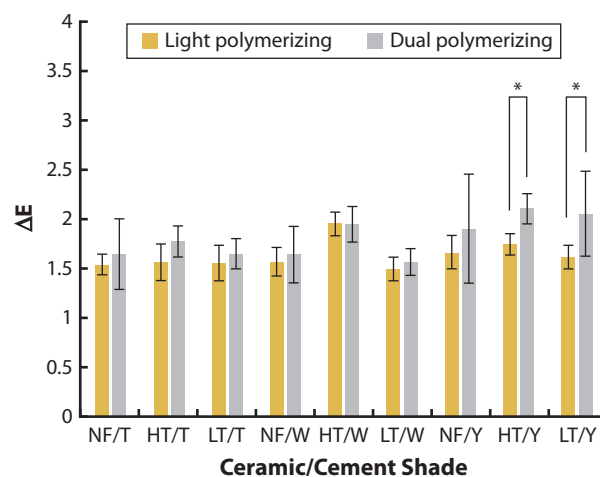
with acidic monomers, thus reducing the occurrence of adverse reactions.[18] Second, in dual-polymerizing cements, the degree of polymerization decreases only when autopolymerization is performed.[21,22] Therefore, sufficient light exposure and rapid polymerization can solve this problem. Additionally, the development of a color-stable initiator that reduces amine or CQ availability and increases the degree of conversion is in progress.[19,20,25] As a result, the color stability of resin cements should continue to improve.

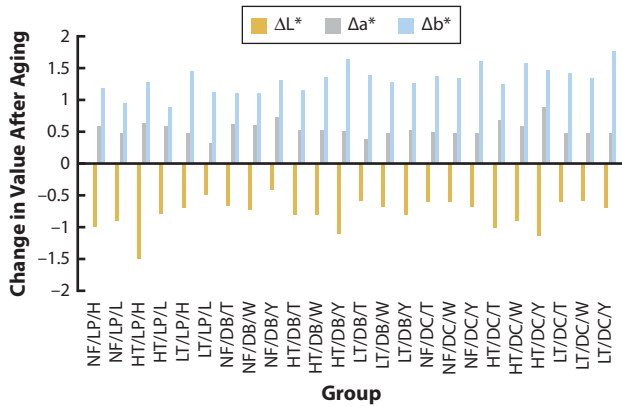In the present study, all groups exhibited changes in L*, a*, and b* values after aging. Decrease in L* values

Figure 8. Change in L* (lightness), a* (green-red), and b* (blue-yellow) values of all groups after second aging. ΔE, color differences; DB, base use in dual-polymerizing cement; DC, base catalyst use in dual-polymerizing cement; H, high-brightness; HT, high translucency lithium disilicate ceramic; L, low-brightness; LP, light-polymerizing cement; LT, low translucency lithium disilicate ceramic; NF, nanofluorapatite ceramic; T, transparent shade; W, white shade; Y, yellow shade.

implies darkening of the specimen, while an increase in a* and b* values implies reddening and yellowing of the specimen, respectively. Bagis and Turgut[4] reported that ceramics get darker and more red and yellow after aging. Moreover, resin cements tend to darken, especially with high pigment content and unreacted components. The greatest change in b* values is brought about by unreacted CQ and oxidized amines. Additionally, hydrolytic degradation of triethyleneglycol dimethacrylate and bisphenol-A glycidyl dimethacrylate in resin cements could be a determining factor in the yellowing effect.[9,15]

This study has some limitations. First, the study mostly used materials from a single manufacturer. Second, the thickness of laminate veneers was 0.5 mm, which is considered the minimum thickness for the evaluation of color change in laminates.[7] The use of various systems from different manufacturers and ceramic thickness is recommended to ensure broad applicability of results. Additionally, since resin cements without amines have been introduced in recent years, studies regarding the color stability of these resin cements would be beneficial.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Relative to other ceramics, high translucent lithium disilicate glass ceramic exhibited a greater tendency for color change. Therefore, transparent cement is recommended over cements of other shades for luting high-translucent ceramics.
2. The lower the brightness of resin cement, the higher the color stability.
3. For luting 0.5-mm-thick laminate veneers with dual-polymerizing cement, light polymerization did not yield better color stability than dual polymerization over time.
4. Aging reduced the L* values and increased the a* and b* values of laminate veneers.

REFERENCES

1. Pinto RC, Chambrone L, Colombini BL, Ishikiriama SK, Britto IM, Romito GA. Minimally invasive esthetic therapy: a case report describing the advantage of a multidisciplinary approach. Quintessence Int 2013;44:385-91.
2. Radz GM. Minimum thickness anterior porcelain restorations. Dent Clin North Am 2011;55:353-70.
3. Chen XD, Hong G, Xing WZ, Wang YN. The influence of resin cements on the final color of ceramic veneers. J Prosthodont Res 2015;59:172-7.
4. Bagis B, Turgut S. Optical properties of current ceramics systems for laminate veneers. J Dent 2013;41:24-30.
5. Morimoto S, Albanesi RB, Sesma N, Agra CM, Braga MM. Main clinical outcomes of feldspathic porcelain and glass-ceramic laminate veneers: a systematic review and meta-analysis of survival and complication rates. Int J Prosthodont 2016;29:38-49.
6. Calgaro PA, Furuse AY, Correr GM, Ornaghi BP, Gonzaga CC. Post-cementation colorimetric evaluation of the interaction between the thickness of ceramic veneers and the shade of resin cement. Am J Dent 2014;27:191-4.
7. Ferrari M, Patroni S, Balleri P. Measurement of enamel thickness in relation to reduction for etched laminate veneers. Int J Periodontics Restorative Dent 1992;12:407-13.
8. Turgut S, Bagis B, Ayaz EA. Achieving the desired colour in discoloured teeth, using leucite-based CAD-CAM laminate systems. J Dent 2014;42:68-74.
9. Almeida JR, Schmitt GU, Kaizer MR, Boscato N, Moraes RR. Resin-based luting agents and color stability of bonded ceramic veneers. J Prosthet Dent 2015;114:272-7.
10. Xing W, Jiang T, Ma X, Liang S, Wang Z, Sa Y, et al. Evaluation of the esthetic effect of resin cements and try-in pastes on ceromer veneers. J Dent 2010;38:87-94.
11. Materdomini D, Friedman MJ. The contact lens effect: enhancing porcelain veneer esthetics. J Esthet Dent 1995;7:99-103.
12. Ledić K, Majnarić I, Milardović S, Ortolan SM, Špalj S, Štefančić S, et al. Analysis of translucency parameter of glass-ceramics fabricated by different techniques. Acta Stomatol Croat 2015;49:27-35.
13. Vichi A, Carrabba M, Paravina R, Ferrari M. Translucency of ceramic materials for CEREC CAD/CAM system. J Esthet Restor Dent 2014;26:224-31.
14. Ozturk E, Chiang YC, Cosgun E, Bolay S, Hickel R, Ilie N. Effect of resin shades on opacity of ceramic veneers and polymerization efficiency through ceramics. J Dent 2013;41:8-14.
15. Archegas LR, Freire A, Vieira S, Caldas DB, Souza EM. Colour stability and opacity of resin cements and flowable composites for ceramic veneer luting after accelerated ageing. J Dent 2011;39:804-10.
16. Pissaia JF, Correr GM, Gonzaga CC, Cunha LF. Influence of shade, curing mode, and aging on the color stability of resin cements. Braz J Oral Sci 2015;14:272-5.
17. Uchida H, Vaidyanathan J, Viswanadhan T, Vaidyanathan TK. Color stability of dental composites as a function of shade. J Prosthet Dent 1998;79:372-7.
18. Kwon TY, Bagheri R, Kim YK, Kim KH, Burrow MF. Cure mechanisms in materials used in esthetic dentistry. J Investig Clin Dent 2012;3:3-16.
19. Shin DH, Rawls HR. Degree of conversion and color stability of the light curing resin with new photoinitiator systems. Dent Mater 2009;25:1030-8.
20. Palin WM, Hadis MA, Leprince JG, Leloup G, Boland L, Fleming GJ, et al. Reduced polymerization stress of MAPO-containing resin composites with increased curing speed, degree of conversion and mechanical properties. Dent Mater 2014;30:507-16.
21. Di Francescantonio M, Aguiar TR, Arrais CA, Cavalcanti AN, Davanzo CU, Giannini M. Influence of viscosity and curing mode on degree of conversion of dual-cured resin cements. Eur J Dent 2013;7:81-5.
22. Arrais CA, Giannini M, Rueggeberg FA. Kinetic analysis of monomer conversion in auto- and dual-polymerizing modes of commercial resin luting cements. J Prosthet Dent 2009;101:128-36.
23. Sanares AM, Itthagarun A, King NM, Tay FR, Pashley DH. Adverse surface interactions between one-bottle light-cured adhesives and chemical-cured composites. Dent Mater 2001;17:542-56.
24. Janda R, Roulet JF, Kaminsky M, Steffin G, Latta M. Color stability of resin matrix restorative materials as a function of the method of light activation. Eur J Oral Sci 2004;112:280-5.
25. Oei JD, Mishriky M, Barghi N, Rawls HR, Cardenas HL, Aguirre R, et al. Development of a low-color, color stable, dual cure dental resin. Dent Mater 2013;29:405-12.

26. Heydecke G, Zhang F, Razzoog ME. In vitro color stability of double-layer veneers after accelerated aging. J Prosthet Dent 2001;85:551-7.
27. Lu H, Powers JM. Color stability of resin cements after accelerated aging. Am J Dent 2004;17:354-8.
28. Wee AG, Monaghan P, Johnston WM. Variation in color between intended matched shade and fabricated shade of dental porcelain. J Prosthet Dent 2002;87:657-66.
29. Silami FD, Tonani R, Alandia-Román CC, Pires-de-Souza Fde C. Influence of different types of resin luting agents on color stability of ceramic laminate veneers subjected to accelerated artificial aging. Braz Dent J 2016;27:95-100.
30. Turgut S, Bagis B. Colour stability of laminate veneers: an in vitro study. J Dent 2011;39:57-64.
31. International Organization for Standardization. ISO 7491: Dental materials—determination of colour stability. Geneva: International Organization for Standardization; 2000. Available at: https://www.iso.org/obp/ui/#iso:std:iso:7491:ed-2:v1:en.
32. Kilinc E, Antonson SA, Hardigan PC, Kesercioglu A. Resin cement color stability and its influence on the final shade of all-ceramics. J Dent 2011;39:e30-6.
33. Turgut S, Bagis B. Effect of resin cement and ceramic thickness on final color of laminate veneers: an in vitro study. J Prosthet Dent 2013;109:179-86.
34. Yilmaz B, Karaagaclioglu L. In vitro evaluation of color replication of metal ceramic specimens using visual and instrumental color determinations. J Prosthet Dent 2011;105:21-7.
35. Powers JM, Sakaguchi RL. Chapter 4: Fundamentals of materials science. In: Craig's restorative dental materials. 13th ed. St Louis: Elsevier; 2012. p. 54-7.
36. O'Brien WJ. Dental materials and their selection. 4th ed. Chicago: Quintessence; 2008. p. 25-38.

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Noteworthy Abstracts of the Current Literature

Influence of the diameter of dental implants replacing single molars: 3- to 6-year follow-up

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Purpose. The aim of this study was to evaluate the influence of the implant diameter on marginal bone remodeling around dental implants replacing single molars after a follow-up period of 3 to 6 years.

Material and methods. Patients who received dental implants with an external hexagon platform in healed sites to support a single metal-ceramic crown in the molar region were recalled to the office. The implantation sites and implant length information were recorded, and the implants were divided according to the implant diameter: regular (RP) or wide (WP). Each implant was assessed by digital periapical radiography, using a sensor holder for the paralleling technique. The marginal bone remodeling was determined as the distance from the implant platform to the first bone-to-implant contact, and the known implant length was used to calibrate the images in the computer software. The follow-up measurements were compared with those obtained from the radiograph taken at the time of prosthetic loading to determine the late bone remodeling. The independent t test was used to compare data.

Results. A total of 67 implants from 46 patients were evaluated with a mean follow-up period of 4.5 ±1.0 years. The RP group comprised 36 implants from 29 patients (mean age: 58.3 ±10.6 years), while 31 implants from 17 patients (mean age: 56.9 ±11.5 years) were included in the WP group. The RP group presented lower survival rates (86.1%) than the WP group (100.0%). Similar marginal bone loss (P<.05) was identified for the RP and WP groups (1.35 ±0.96 mm and 1.06 ±0.70 mm, respectively).

Conclusions. Although wide-diameter implants exhibited lower incidence failures, the bone levels were similar after the prosthetic loading around regular- and wide-diameter implants supporting single molar crowns.

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