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Translucency changes of direct esthetic restorative materials after curing, aging and treatment

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The purpose of this article was to review the changes in translucency of direct esthetic restorative materials after curing, aging and treatment. As a criterion for the evaluation of clinical translucency changes, visual perceptibility threshold in translucency parameter difference (ΔTP) of 2 was used. Translucency changes after curing were perceivable depending on experimental methods and products (largest ΔTP in resin composites = 15.9). Translucency changes after aging were reported as either relatively stable or showed perceivable changes by aging protocols (largest ΔTP in resin composites = -3.8). Translucency changes after curing, aging and treatment were perceivable in several products and experimental methods. Therefore, shade matching of direct esthetic materials should be performed considering these instabilities of translucency in direct esthetic materials. (*Restor Dent Endod* 2016;41(4):239-245)

Key words: Aging; Curing; Restorative material; Translucency

Introduction

Translucent property of esthetic materials enhances the color harmonization with surrounding or adjacent teeth/restorations and the color blending at restoration-tooth interface.[1-4] The Commission Internationale de l'Eclairage (CIE) color coordinates are generally used in dental color study.[5] For translucency determination, two indices, translucency parameter (TP) and contrast ratio (CR), are widely used. TP is obtained by calculating the color difference of a specimen over an ideal white and black background.[6] CR is calculated from the spectral reflectance (Y) of the specimens with black (Y_b) and white (Y_w) backgrounds to give Y_b/Y_w.[7]

For the clinically relevant evaluation of translucency changes in this review, previously reported visual perceptibility threshold was used as the criterion, which indicates that the changes higher than this threshold (ΔCR > 0.07 or ΔTP > 2) would be perceivable by the naked eyes.[8] For the determination of this value, relationship between the subjective visual assessment of differences in the translucency and CR differences was determined.[8] Each participant's ability to distinguish between specimens of differing translucency was determined by calculating the mean perceivable minimal difference in CR (ΔCR). As results, mean ΔCR was 0.07, which could be transformed into ΔTP value of 2 when TP values were around those of human enamel (TP = 15 to 19) using a regression equation.[9]

In the previous articles on the translucency of dental substances,[3,10] the following subjects such as translucency of teeth and dental ceramics, measuring methods and control of translucency were reviewed. The purpose of the present review was to evaluate the translucency changes after curing, aging and treatment of direct esthetic restorative materials based on the criterion of visual perceptibility threshold (ΔTP > 2). For this, PubMed search was carried out up to 2015 identifying papers on the translucency changes of dental direct esthetic restorative materials after curing, aging and/or treatment published in English. Additional articles were searched by hand-searching based on the references of the included papers. As to the statistical significance of the data included in the present article, it was regarded as significant if the *p* value was lower than 0.05.

Review

Translucency changes after curing

Curing-dependent color and translucency changes of direct esthetic materials indicate cured material should be used as a shade guide for optimal shade matching with tooth. Therefore, for a precise shade match, direct shade matching of this kind of materials should be performed by using the cured material.[11,12] When the translucency changes caused by curing, aging and treatment were determined simultaneously in one study, those reports were included in this section.

Changes in TP of resin composites and glass ionomers after light curing and submersion in water were determined based on 2 mm thick specimens.[13] As results, after curing, TP increased in resin composites, and after water immersion, it showed decrease or increase by the brand and shade. Relatively large optical changes after curing and subsequent submersion in water indicated that these changes should be taken into account during initial clinical appearance match. Regarding translucency changes after light curing of resin composites,[12] one product showed a significant increase, although no difference was observed in the other products.

Changes in TP after curing and accelerated aging for 150 kJ/m^{2} of resin composites used to restore bleached teeth were determined, and were compared with those of conventional shades based on 2 mm thick specimens.[14] Mean change in TP after curing (= TP after curing - TP before curing) of bleached shades in one brand was 15.9, and was 5.3 in the other brand, while those of conventional shade were 3.4 and -2.3, respectively. Mean change in TP after aging of bleached shades in one brand was -0.5, and was -0.2 in the other brand, while that of conventional shade was -0.5 and -0.2, respectively. In both shade groups, changes in TP after curing were

perceivable, but were not perceivable after aging based on the threshold ΔTP of 2.[8,9] In other study, changes in TP of resin composites for bleach shades after curing were evaluated based on 2 mm thick specimens.[11] As results, TP values of cured resin composites varied from 2.0 to 7.1. Light curing caused increase in TP (+0.7) in microhybrids and decrease (-0.7) in microfills. In this study,[11] changes in TP were lower than perceivable limit (ΔTP < 2), which was different from the results of the other study.[14] Differences in background color in two studies might have been one reason, and other reasons such as difference in products may also have influenced these discrepancies.

Changes in TP after curing, polishing and thermocycling (TC, 2,000 cycles between 5 and 55℃) of nano-filled resin composites were determined based on 2 mm thick specimens.[15] Composites were divided into two shade groups of enamel (EN) and translucent (TL). Hybrid composite was used as a control (CL). To determine the influence of water content in specimens on TP, color after polishing was measured after storage in dry oven for 24 hours (dry condition), and after immersion in distilled water for 24 hours and blot drying (wet condition). Mean TP values after curing of three groups in the order of EN, TL, and CL group were 13.4, 33.0, and 12.3, respectively. TP values of TL shades were higher than those of EN shades regardless of the specimen condition. TP increased after curing in EN shades, but decreased in TL shades (Table 1). TP values after TC decreased in EN shades but did not change in TL. Therefore, changes in translucency after curing, polishing and TC varied by the shade group, and the changes in TP after curing were perceivable (ΔTP > 2).[8,9]

Changes in TP in eight brands of A2 shade resin composites after curing, polishing and TC were determined based on 2 mm thick specimens.[16] TC was performed for 2,000 cycles, and color was measured after blot drying. Range of TP was 7.1 - 17.2 (mean: 11.1) before curing, 11.5 - 15.8 (mean: 13.9) after curing, 11.4 - 17.6 (mean: 14.5) after polishing, and 11.2 - 17.4 (mean: 14.4) after TC (Table 2). TP values tended to increase after curing. Changes in TP values after curing were significant in all resin composites investigated. Although the shade designation of all the investigated composites was A2, TP values and the translucency changes after curing, polishing and TC varied by the brand. Changes in TP after curing, polishing and TC were perceivable compared with those before curing (ΔTP > 2).

Translucency of indirect (BelleGlass NG, BG, Kerr, Orange, CA, USA) and direct (Estelite Sigma, ES, Tokuyama, Tokyo, Japan) resin composites, each composed in three shade groups, before and after curing was compared by the material and shade group combination.[17] As results, TP values of both materials were influenced by curing, and the mean TP values in each shade group of resin composites before curing were in the range of 7.7 (BG-OD) to 16.9 (ES-

Table 1. TP values after curing, polishing and thermocycling of nano-filled resin composites

SG	Code	Before cure (Group 1)	After cure (Group 2)	After polish (dry) (Group 3)	After polish (wet) (Group 4)	After TC (Group 5)	DG[a]
EN (I)[b]	A1	9.9 ± 0.4	12.8 ± 0.4	13.2 ± 0.4	13.0 ± 0.4	11.7 ± 0.6	1 < 5 < 2,4,3
	A2	9.5 ± 0.5	12.5 ± 0.2	13.1 ± 0.3	12.9 ± 0.3	11.7 ± 0.2	1 < 5 < 2 < 3
	A3	9.9 ± 0.5	12.9 ± 0.1	13.8 ± 0.2	13.6 ± 0.2	12.4 ± 0.3	1 < 5 < 2 < 4,3
	B1	10.4 ± 0.4	13.4 ± 0.3	14.4 ± 0.6	14.2 ± 0.6	13.1 ± 0.5	1 < 5,2 < 4,3
	B2	10.1 ± 0.5	12.9 ± 0.4	13.7 ± 0.3	13.4 ± 0.3	12.6 ± 0.2	1 < 5< 2,4,3
	D2	7.4 ± 0.3	11.1 ± 0.8	12.0 ± 0.2	11.8 ± 0.2	11.1 ± 0.2	1 < 5 < 2,4,3
	WE	15.5 ± 0.4	18.6 ± 0.5	20.1 ± 0.4	19.5 ± 0.4	18.5 ± 0.7	1 < 5 < 2,4,3
	AVG	10.4 ± 2.4	13.4 ± 2.2	14.3 ± 2.5	14.1 ± 2.4	13.0 ± 2.4	1 < 5 < 3
TL (II)	GR	41.0 ± 0.6	32.1 ± 0.7	34.3 ± 1.0	34.4 ± 1.2	34.5 ± 1.2	2 < 3,4,5 < 1
	VL	36.7 ± 1.3	31.4 ± 1.0	32.8 ± 1.5	32.4 ± 1.5	32.4 ± 1.3	2,4,5,3 < 1
	YL	43.9 ± 0.6	35.5 ± 0.5	37.4 ± 0.7	37.2 ± 0.7	37.4 ± 0.4	2 < 4,5,3 < 1
	AVG	40.5 ± 3.1	33.0 ± 1.9	34.8 ± 2.3	34.6 ± 2.3	34.8 ± 2.3	2,4,5,3 < 1
CL (III)	A2	9.9 ± 0.2	12.3 ± 0.2	13.7 ± 0.4	13.4 ± 0.4	13.0 ± 0.4	1 < 2 < 5 < 3
DG2		III,I < II	III,I < II	III,I < II	III,I < II	III,I < II	

This table was cited from the reference 15.
TP, translucency parameter; TC, thermocycling; SG, shade group; EN, enamel shade; TL, translucent shade; CL, control; WE, white enamel shade; AVG, average; GR, gray; VL, violet; YL, yellow.
[a]Different groups by the specimen condition. '<' means significantly different group marker (Scheffe test, $p < 0.05$). ',' means no significantly different groups.
[b]These numeric codes are used in DG2. The expression is the same as DG.

Table 2. TP values after curing, polishing and thermocycling of A2 shade resin composites

Code	Before cure (Group 1)	After cure (Group 2)	After polish (Group 3)	After TC (Group 4)	DG[a]
CHR	11.2 ± 0.1[4]	15.8 ± 0.1[5]	17.6 ± 0.8[5]	17.4 ± 0.9[5]	1 < 2 < 4,3
CLF	10.7 ± 0.3[3,4]	14.7 ± 0.4[4]	14.1 ± 0.2[2,3]	13.5 ± 0.1[2,3]	1 < 4 < 3 < 2
ESX	13.8 ± 0.3[5]	12.5 ± 0.2[2]	13.5 ± 0.6[2]	13.3 ± 0.6[2]	2 < 4,3,1
FSP	8.8 ± 0.5[2]	11.5 ± 0.4[1]	11.4 ± 0.4[1]	11.2 ± 0.6[1]	1 < 4,3,2
PAE	17.2 ± 0.7[6]	15.1 ± 0.3[4]	15.5 ± 0.6[4,5]	15.5 ± 0.6[4]	2,3,4 < 1
PO4	8.3 ± 0.4[2]	13.4 ± 0.3[3]	14.7 ± 0.3[3,4]	14.5 ± 0.5[3,4]	1 < 2 < 4,3
TEC	10.1 ± 0.4[3]	15.3 ± 0.6[4,5]	16.2 ± 0.9[5]	16.9 ± 0.8[5]	1 < 2 < 3,4
TPH	7.1 ± 0.1[1]	13.0 ± 0.1[2,3]	13.2 ± 0.3[2]	12.9 ± 0.4[2]	1 < 4,2,3
Mean	11.1 ± 3.1	13.9 ± 1.5	14.5 ± 1.9	14.4 ± 2.1	1 < 2,4,3

This table was cited from the reference 16.
Same superscript number means not significantly different group in the same column.
TP, translucency parameter; TC, thermocycling; CHR, Charisma; CLF, Clearfil AP-X; ESX, Esthet X; FSP, Filtek Supreme; PAE, Palfique Estelite; PO4, Point 4; TEC, Tetric Ceram; TPH, TPH Spectrum.
[a]Different groups by the specimen condition. '<' means significantly different group marker (Scheffe test, $p < 0.05$). ',' means no significantly different groups.

AS), and those after curing were in the range of 10.0 (BG-OD) to 21.5 (BG-EN). In this, OD indicates opaceous dentin shade, AS indicates additional shade, and EN indicates enamel shade in the brands. Changes in TP after curing and finishing of resin composites were compared.[18] Light and dark, enamel and dentin shades were selected. As results, translucency increased in all groups except one and the amount of changes in TP varied from -0.4 to 8.9. Curing caused remarkable translucency changes, which were product and shade dependent.

Influence of the type of curing light on the changes in TP of resin composites was determined.[19] Specimens were cured with quartz-tungsten-halogen (QTH) or light-emitting diode (LED) light. The results indicated that there was significant difference between ΔTP values obtained using QTH and LED curing light. Changes in TP of resin composites after curing were compared using two color difference metric formulae, CIELAB (ΔE^*_{ab} and ΔTP) and CIEDE 2000 (ΔE^*_{00} and ΔTP_{00}, which mean color difference calculated based on the CIEDE 2000 formula and difference in translucency parameter calculated based on the CIEDE 2000 color coordinates, respectively) based on 2 mm thick specimens.[20] Mean curing-dependent color changes were ΔE^*_{00} = 4.5 (± 2.1) and ΔE^*_{ab} = 5.5 (± 2.7), and mean curing-dependent translucency changes were ΔTP_{00} = 0.8 (± 0.8) and ΔTP = 0.9 (± 0.8). Curing-dependent changes in color and translucency were highly varied, and TP generally increased after curing. The strong correlation (r > 0.97) between the two color difference formulae indicates that the limitations of the CIELAB color system did not appear to be a problem when evaluating dental resin composites.

Translucency changes after aging

Varied aging protocols have been employed to determine the changes in translucency during clinical service. Accelerated aging in aging chamber, TC, light exposure with/without water storage, immersion in hot water, and immersion in salivary enzymes were used as protocols.

Translucency changes in hybrid and microfilled resin composites after light exposure with and without water storage were determined *in vitro*.[21] The results suggested that resin-based materials underwent measurable changes due to daylight exposure, and increased changes occurred under the influence of water storage. Translucency changes of resin composites for metal-free crowns and conventional resin composites were examined.[22] Specimens were immersed in 60℃ distilled water for up to 8 weeks. Changes in translucency were evaluated by CR. After water immersion, one of composites for metal-free crowns and one of conventional composites demonstrated significant increases in CR (6 to 7%) and a decrease in translucency. The other five composites did not show any significant difference in CR before and after water immersion,

indicating that their translucency did not change.

Influence of accelerated aging on TP of resin composites for bleach shades was evaluated based on 2 mm thick specimens.[23] Accelerated aging was performed in an increment of 150 kJ/m² up to 450 kJ/m². TP values at baseline were 0.9 - 4.3 for microhybrid (MH) composites and 1.4 - 2.2 for microfill (MF) composites. The range of TP values after aging for 150, 300, and 450 kJ/m² were 0.8 - 4.0 for MH and 0.9 - 2.0 for MF, 0.7 - 4.3 for MH and 1.5 - 2.0 for MF, and 0.8 - 4.1 for MH and 0.9 - 2.4 for MF, respectively. Mean ΔTP values after 150, 300, and 450 kJ/m² were 0.07, 0.12, and 0.16 for MH and 0.14, 0.11, and 0.00 for MF, respectively. ΔTP (= TP at baseline - TP after aging 450 kJ/m²) ranged from -1.1 to 1.7 for MH and from -0.1 to 0.3 for MF. Therefore, TP was relatively stable after aging in both of MH and MF composites. These changes were not perceivable based on the criterion of the present article (ΔTP < 2).

It was confirmed that the changes in translucency after curing significantly influenced the overall color changes.[19] Assuming that color changes after aging were related to changes in translucency, correlations between the changes in color and the changes in scattering coefficient (ΔS), absorption coefficient (ΔK), and light reflectivity (ΔRI) after accelerated aging were determined with glass ionomer, resin-modified glass ionomer, compomer and resin composite.[24] After baseline measurement, specimens were aged for 150 kJ/m². In resin composite and compomer, ΔS, ΔK, and ΔRI values were nearly zero, whereas ΔS was as high as 8.9 in glass ionomer. Therefore, changes in scattering and absorption properties were closely related with changes in color, especially in glass ionomer. Differences in TP of glass ionomer, resin-modified glass ionomer, compomer, and resin composite of A2 shade before and after accelerated aging (150 kJ/m²) were determined based on 1 mm thick specimens.[25] As results, translucency of four materials was affected differently by accelerated aging. Changes in glass ionomer was the highest (ΔTP = -15.9), followed by resin-modified glass ionomer (-10.4), compomer (-2.3), and resin composite (-0.3).

Changes of TP in eight resin composites (41 shades) after TC were evaluated based on 1 mm thick specimens.[26] TC was performed for 5,000 cycles between 5℃ and 55℃, and color was measured after blot drying. As results, ΔTP values were in the range of -3.8 to 0.1, and were influenced by the brand of resin composite. Translucency changes of porcelain-repairing resin composites, compared with porcelain, were determined after TC based on 2 mm thick specimens.[27] The range of ΔTP was 0.45 to 0.96 in porcelain, and from -1.31 to 1.91 in resin composites. Therefore, it was concluded that the discrepancy in the changes of color and translucency during clinical service between porcelain and porcelain-repairing resin composites

should be considered when selecting repairing materials.

Resin composites are degraded by salivary enzymes;[28] therefore, the influence of salivary enzyme on the translucency of resin composites was determined.[29] Changes in the translucency of resin composites after storage in the salivary enzyme esterase (ETE, porcine liver esterase, 400 mU/mL) were determined after immersion in phosphate-buffered saline (PBS, reference) or ETE for 9 weeks. TP values changed significantly after immersion in PBS and ETE. TP changes were influenced by the brand of resin composites, but not by the immersion solutions. Therefore, it was concluded that the enzymatic effects of saliva did not adversely alter the translucency of resin composites. Since esterase molecules are large compared to the polymer network, it seems that the reaction of ETE that occurred was just surface diffusion and surface degradation.[30]

Translucency stabilities of direct and indirect resin composites after thermocycling for 5,000 cycles were evaluated.[31] One direct (16 shades) and two indirect resin composites (16 and 26 shades) were investigated based on 1 mm thick specimens. As results, ΔTP values were -1.2 to 0.7 for direct composites and -2.0 to 1.8 for indirect composites. Therefore, translucency stabilities of resin composites varied depending on type, brand or shade group.

Translucency changes after treatment and coating

Changes in the translucency of resin composites following a series of immersions in organic and chemical substances were investigated based on 1.2 mm thick specimens.[32] TP values were determined at baseline, and after sequential immersions: step 1, enzymatic softening with porcine liver esterase (a substitute for salivary esterase); step 2, organic substances such as mucin and serum, and phosphate-buffered saline (PBS) as a control; step 3, chemical alteration agents such as chlorhexidine (CH) and carbamide peroxide (CP); step 4, stain absorption with 2% methylene blue. As results, porcine liver esterase caused small changes in TP (ΔTP = -0.5 to 0.2). After step 2, mucin and serum caused small and similar changes in TP (DTP = -0.7 to 1.0, -0.3 to 1.2, respectively) compared with PBS group (DTP = -0.2 to 1.2). After step 3, chlorhexidine and carbamide peroxide also caused small changes in TP (DTP = -1.5 to 2.2, -0.5 to 1.9, respectively). After step 4, changes in TP were very high and variations by the material and immersion protocols were clearly observed (DTP = -13.4 to -2.5). After step 4, mucin and serum groups showed generally small changes in TP compared with PBS group. It is a possibility that the high changes in TP after immersion in methylene blue is an indication of dye absorption which might reflect the degree of resin composite degradation. From these results, it was found that degradation of resin composites was mainly composite product dependent.

Applying the criterion of the present review, decreases in TP were perceivable after methylene blue staining (ΔTP > 2). Staining susceptibility of silorane, ormocer, methacrylate and compomer exposed on the long term (99 days) to various staining agents (red wine, juice, coke, tea, and coffee) was determined.[33] As results, changes in TP varied from 0.3 (air control) to 21.1 (juice). Color stability in relation to the opacity of a nanocomposite after immersion in different types of natural and artificial staining solutions was evaluated.[34] As results, no significant differences were found among various opacities of this composite regarding the translucency changes.

Regular use of mouthrinses, particularly when combined with the use of air-powder polishing, could affect the appearance of esthetic restorations. Influence of air-powder polishing on the translucency of resin composites immersed in different mouthrinses was evaluated.[35] Specimens were allocated into two groups according to the surface treatment: exposure to air-powder polishing (10 seconds) or nonexposure (control), and they were assigned into four subgroups, according to the mouthrinses. Translucency was measured with a transmission densitometer. As results, distilled water (control) presented higher translucency values (86.7%), whereas mouthrinse groups showed lower translucency values (72.7 to 74.1%). Air-powder polishing alone had no effect on material translucency; however, air-powder polishing increased the changes in translucency associated with the mouthrinses. Translucency percent was gradually decreased from 1 week of immersion up to 4 months. It was also reported that the thickness and surface roughness were major factors affecting the absolute translucency of adhesively-luted restorative materials.[36]

Polymer-based tooth coating materials were developed to meet the demand for esthetic improvement, apart from bleaching. One of these materials consists of a self-etching primer solution, light curing resin coating material and surface glazing material, and this material can be applied on the enamel surface to improve the esthetic appearance of discolored tooth.[37,38] Translucency and color change of simulated heavily discolored teeth using tooth coating materials and flowable resin composites were evaluated with the thickness range of 0.2, 0.3, 0.5, 1, and 2 mm.[37] Five shades of coating material and two shades of flowable resin composites were investigated. As results, coating material showed lower translucency than flowable resin composites. Therefore, this material showed the potential to improve the appearance of heavily discolored teeth. Color-masking ability of two polymer-based paint-on temporary coating materials was estimated.[38] Disk specimens (0.25 to 2 mm thick) were prepared and TP values were determined. Masking effect was also calculated as the color difference between a specimen over a black background and black background itself. As results, TP values decreased as the thickness of specimens increased,

and non-linear regressions were shown between the specimen thickness and TP value for all the materials investigated. TP values of one product showed significant differences between each shade, ranging from 20.0 to 46.4 at 0.25 mm in thickness. The other product showed narrower ranging TP values from 20.0 to 23.5 at 0.25 mm. Masking effect was correlated with TP values.

Conclusions

The criterion for the evaluation of translucency changes was established whether the differences were perceivable by the naked eyes. Translucency difference in the contrast ratio (ΔCR) of 0.07 was regarded as the perceivable limit, which could be transformed into the ΔTP value of 2.

Translucency changes after curing of resin composites were perceivable in some studies and not perceivable in other studies depending on the experimental methods and products (largest ΔTP in resin composites = 15.9). Varied aging protocols have been employed for the determination of changes in translucency during clinical service. Accelerated aging, thermocycling, light exposure with/without water storage, immersion in hot water and salivary enzymes were used. Translucency changes after aging were relatively stable or showed perceivable difference depending on the aging protocol and products (largest ΔTP in resin composites = -3.8).

Translucency changes after curing, aging and treatment were perceivable in several products and experimental methods. Therefore, shade matching of direct esthetic materials should be performed considering these instabilities of translucency in direct esthetic materials.

Conflict of Interest: No potential conflict of interest relevant to this article was reported.

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