Accelerated Aging Effects on Color and Translucency of Bleaching-Shade Composites

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ABSTRACT

Purpose: This study was performed to evaluate the influence of accelerated aging on the color and translucency parameter (TP) of bleaching-shade resin composites.

Materials and Methods: Thirty-three bleaching shades and two control conventional shades of microhybrid (MH) and microfill (MF) resin composite specimens ($n = 5$) were aged in an accelerated aging chamber set to standard CAM 180 cycles. One side of each specimen was evaluated for surface color and TP changes compared with baseline in increments of 150 kJ/m^2 for intervals up to 450 kJ/m^2 using a spectrophotometer. A $\Delta E^* \geq 3.7$ was considered to be a poor match, and the total TP range was divided into three equal parts representing low, medium, and high translucency. Data were analyzed with analysis of variance.

Results: Compared to the baseline, ΔL^*, Δa^*, Δb^*, and ΔE^* ranges at 450 kJ/m^2 were –0.8 to 5.0, –0.6 to 1.2, –8.3 to 0.0, and 0.7 to 8.6 for MH and 0.2 to 1.3, 0.1 to 1.3, –2.5 to 1.1, and 1.7 to 2.7 for MF composites. Scheffé's *S* intervals ($p = .05$) for comparisons of ΔL^*, Δa^*, Δb^*, and ΔE^* values of MH composites between baseline and 450 kJ/m^2 were 1.6, 0.6, 1.7, and 1.5, respectively. Corresponding Tukey-Kramer intervals for MF composites were 0.7, 0.3, 0.6, and 0.6, respectively. TP values at baseline ranged from 0.9 to 4.3 for MH and from 1.4 to 2.2 for MF composites, whereas ΔTP for baseline minus 450 kJ/m^2 ranged from –1.1 to 1.7 for MH and from –0.1 to 0.3 for MF composites. Scheffé's *S* interval ($p = .05$) for comparisons of ΔTP values of MH composites for baseline minus 450 kJ/m2 was 1.0. Corresponding Tukey-Kramer interval for MF composites was 0.4.

Conclusions: Aging-dependent color changes at 450 kJ/m^2 were above the limit that indicated a poor match for 18/26 MH, while corresponding values for microfills were within acceptable range. Accelerated aging generally caused decreases in L* (specimens became darker) and a* values (specimens became redder), while b* values increased (specimens became more chromatic) for both MH and MF composites. TP was relatively stable during aging for both MH and MF composites.

CLINICAL SIGNIFICANCE

Esthetics of resin composite restorations should be routinely reexamined since aging may cause significant color changes. After aging, composite bleaching shades generally became darker and more saturated for both MH and MF composites. Microhybrids were less color stable than microfills, but TP values were relatively stable for both composite types.

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The real "life" of dental material begins after placement in the patient's mouth. Although color, translucency, and other parameters related to esthetics can be judged immediately, validation of these properties should be done on a long-term basis as well.

The most widely accepted color notation systems have been developed by Commission Internationale de l'Eclairage (CIE).[1,2] The CIE L*a*b* (CIE 76) system is predominantly used in dentistry-related studies. Color coordinates of the CIE L*a*b* system are lightness (vertical, achromatic coordinate; value), L*, and chromatic coordinates: a* (horizontal, green/red coordinate) and b* (horizontal, blue/yellow coordinate). Saturation, C*, represents the difference of a specific color in relation to gray color of the same lightness (pale and strong colors), whereas hue, H°, enables differentiation of "color families" (eg, red, green, and blue). C* and H° are polar coordinates, derived from the known a* and b* values. The degree of color difference between the compared colors is expressed in ΔE^* units. Total color difference can be further divided into color coordinate differences: ΔL^*, Δa^*, Δb^*, ΔC^*, $\Delta H°$.[2] In dentistry a $\Delta E^* \leq 2.0$ is conventionally considered to be a limit of clinically acceptable color difference,[3] whereas $\Delta E^* \geq 3.7$ represents a poor match.[4]

Although the terms *transparent* and *translucent* are sometimes used synonymously, there are differences between these two optical properties of a material. Transparent materials allow complete transmission of light; thus no light is reflected (they are completely clear). An object behind a transparent material will not appear obscured. Translucent materials allow partial transmission of light, and thus some light is reflected as well. An object behind a translucent material will not appear obscured. Opaque materials are nontransparent and nontranslucent in that they do not allow any transmission of light.[5,6]

The accelerated aging effects on color have been investigated using various dental materials (Table 1): composites,[7–10] provisional materials,[11–13] porcelains,[14] ceramic polymers,[15] veneering materials,[16,17] fluid resin acrylics,[18] denture base resins,[19] soft denture liners,[20] hybrid ionomers,[21] and resin cements.[22,23] In addition to differences among materials, differences in equipment and research methods used in these studies have resulted in a multiplicity of results and conclusions.

The major components of a resin composite are organic polymer matrix, inorganic filler particles, coupling agent, and the initiator-accelerator system. Composites can be classified by the particle size, shape, and distribution of filler. In accordance with the type of filler particles, composites are classified as microhybrids or microfills. Microhybrid (MH) composites contain irregularly shaped glass or quartz particles of fairly uniform diameter. They usually have a distribution of two or more sizes of fine particles with average diameters of 0.4 to 3 µm plus a microfine filler of 0.04 to 0.2 µm in diameter (5–15%). They contain 60 to 70% filler by volume, which corresponds to 77 to 84% by weight. Microfill (MF) composites are composed of silica with a very high surface area (particle diameter 0.04–0.2 µm). Owing to a high surface area, only 25% by volume or 38% by weight is added to the oligomer to keep the appropriate consistency for clinical purposes.[5]

Bleaching-shade composites were introduced as a logical answer to the success of tooth bleaching procedures, and they are also divided into microhybrids and microfills. Since bleaching-shade composites are relatively new materials, a comparative study of their long-term color stability has not yet been published. Furthermore, aging-dependent changes in translucency parameter (TP) have not been thoroughly investigated in prior studies. The purpose of this study was to evaluate in vitro accelerated aging effects on the color and TP for MH and MF bleaching-shade composites and two control conventional shades using reflection spectrophotometry. The hypothesis was that there would be no differences in artificial aging-dependent changes in color and translucency of the tested materials.

MATERIALS AND METHODS

Thirty-three bleaching shades of MH and MF composites from

TABLE 1. ACCELERATED AGING STUDIES: MATERIALS, METHODS, AND RESULTS.

Study	Materials	Methods	Results
Lee YK et al[7]	Compomers and resin-based composites	150 kJ/m^2; spm	$\Delta E^* = 1.1–3.9$, mainly influenced by the material
Powers JM et al[8]	7 commercial composite resins, 1 unfilled resin, 3 glazes	900 h of aging; spm and visually (Munsell tabs, [GretagMacbeth LLC, New Windsor, NY, USA])	Lower values of luminous reflectance and excitation purity and higher values of dominant wavelength and contrast ratio compared to baseline
Powers JM et al[9]	3 anterior composites, 4 posterior composites	300 h of aging; spm	Composites became darker, more chromatic, and more opaque
Powers JM et al[10]	7 commercial composites	900 h of aging in increments of 300 h; spm	Composites became darker, more chromatic, and more opaque
Yaman P et al[11]	5 provisional resins	6 h of aging; clrm	$\Delta E^* = 1.7–13.8$
Doray PG et al[12]	11 provisional restorative materials	60 kJ/m^2 in increments of 15 kJ/m^2; spm	For 7 of 11 materials, $\Delta E^* = 3.4–9.4$ after aging of 60 kJ/m2
Doray PG et al[13]	5 acrylic resin and 7 resin composite provisional materials	60 kJ/m^2; spm	$\Delta E^* = 2.0–8.0$ for acrylic resins and 0.5–17.8 for composites
Razzoog ME et al[14]	2 different dental porcelains	900 h of aging; clrm	Neither porcelain had "noticeable" changes after 900 h of aging
Douglas RD[15]	4 indirect resins, 1 direct resin, 1 dental porcelain	300 h of aging in increments of 150 h; clrm	After 300 h of aging, $\Delta E^* = 0.6–3.4$, clinically acceptable values
Heydecke G et al[16]	Porcelain laminates (alumina shell/feldspathic porcelain)	300 h of aging; clrm	ΔE^* values were not statistically significant compared with a level of 3 ΔE^* units
Powers JM, Fan PL[17]	5 commercial plastic veneering materials	900 h of aging in increments of 300 h; spm	After aging for 900 h, changes in color were minimal and difficult to detect visually
Wang X et al[18]	Heat- and chemically activated denture base acrylics	450 kJ/m^2 in increments of 150 kJ/m^2; spm	3 heat-activated acrylics tested were more color stable than were 2 of the chemically activated acrylics, whereas 1 chemically activated acrylic was color stable
May KB et al[19]	7 conventional and 1 microwave heat-cured denture base materials	900 h of aging in increments of 300 h; spm	ΔE^* values were significant for all materials, but it was not visually noticeable for 1 of them
Anil N et al[20]	2 autopolymerizing and 3 heat-polymerizing soft lining materials	900 h of aging; spm	Heat-polymerized soft liners were more color stable than were autopolymerized soft liners
Davis BA et al[21]	3 commercial hybrid ionomers	150 kJ/m^2; spm	Hybrid ionomers changed color significantly and perceptibly; ΔE^* varied in the range of 6.7–27.9
Noie F et al[22]	3 shades of 3 resin cements (both light and dual cured)	179 h of aging; spm	Most differences between light- and dual-polymerized samples were significant, but none was perceptible
Hekimoglu C et al[23]	Light-cured, dual-cured, and self-cured resin cements	900 h of aging in increments of 300 h; spm	ΔE^* varied in the acceptable range of 1.9–2.7; different aging times caused no significant differences in ΔE^*, ΔC^*, or ΔH°

clrm = colorimeter; spm = spectrophotometer.

10 manufacturers and two conventional shades from two manufacturers were analyzed (Table 2). Five composite specimens (10 mm in diameter and 2 mm thick) of each shade were fabricated in polytetrafluoroethylene cylindric molds.[6] Composite was loaded into the molds and pressed between two glass slides lined with polyester film (Mylar®, DuPont, Wilmington, DE, USA). The specimens were cured for 60 seconds using a standard halogen lamp (Demetron® 501, Kerr/Demetron, Danbury, CT, USA). The energy of the curing light was monitored and maintained between 650 and 760 mW/cm². Specimens were

TABLE 2. RESTORATIVE MATERIALS TESTED.

Manufacturer	Material	Shade	Code	Lot
Microhybrid				
Vident, Brea, CA, USA	3-D Direct®	EN2	3-D/EN2	008097
		0M2	3-D/0M2	008109
		OP0M2	3-D/OP0M2	008104
Dentsply/Caulk, York, PA, USA	Esthet X™	White	ES-X/W	000712
		XL	ES-X/XL	0003091
	TPH Spectrum®	BW	TPH/BW	000413
		XL	TPH/XL	000612
Hereaus Kulzer, South Bend, IN, USA	Charisma®	SLO	CH/SLO	010023
		SLT	CH/SLT	020122
		SL	CH/SL	030026
Kerr, Orange, CA, USA	Point 4®	XL1	P4/XL1	102A11
		XL2	P4/XL2	0121108
		XL3	P4/XL3	003E26
3M ESPE, St. Paul, MN, USA	Filtek™ Z250	B0.5	Z250/B0.5	20010410
Ivoclar Vivadent, Amherst, NY, USA	Tetric Ceram®	Bleach L	TC/L	C22516
		Bleach XL	TC/XL	C25928
Coltene/Whaledent, Mahwah, NJ, USA	Synergy®	Super White N	SYN/N	JJ069
		Super White O	SYN/O	JJ069
		Super White P	SYN/P	JJ069
Cosmedent, Chicago, IL, USA	Renamel® Universal	SB1	RU/SB1	011312 A
		SB2	RU/SB2	011414 A
		SB3	RU/SB3	011915 A
Bisco, Schaumburg, IL, USA	Renew®	B0	RN/B0	0100001921
Ultradent Products Inc., South Jordan, UT, USA	Vitalescence™	PN	V/PN	1184
		PA	V/PA	1185
		PF	V/PF	443
Microfilled				
Hereaus Kulzer	Durafill® VS	SLO	DF/SLO	010121
		SSL	DF/SSL	010121
		SL	DF/SL	030123A
3M ESPE	Filtek™ A110	B0.5	A110/B0.5	20001205
Cosmedent	Renamel® Microfill	SB1	RM/SB1	004529 M
		SB2	RM/SB2	004530 B
		SB3	RM/SB3	004631 K
Control				
Vident	3-D Direct®	1M2	3-D/1M2	007010
Kerr	Herculite® XRV	B1	XRV/B1	105450

stored in a dark environment in a 37°C incubator prior to testing.

Unpolished specimens were aged in an accelerated aging chamber (Atlas Ci35A Xenon® Weather-Ometer, Atlas Material Testing Technology LLC, Chicago, IL, USA) set to standard CAM 180 cycles. One surface of each specimen was exposed to a controlled irradiance xenon arc filtered through borate borosilicate glass at 0.55 W/m^2 at 340 nm, a black panel temperature of 70°C (light cycle) and 38°C (dark cycle), a dry bulb temperature of 47°C (light cycle) and 38°C (dark cycle), and a humidity of 50% (light cycle) and 95% (dark cycle). The test cycle was 40 minutes light only, 20 minutes light plus front water spray, 60 minutes light only, and 60 minutes dark plus back water spray.

Colorimetric data at baseline were evaluated for changes in increments of 150 kJ/m^2 for intervals up to 450 kJ/m^2 at 340 nm using a d/8° spectrophotometer (Color-Eye® 7000, GretagMacbeth LLC, New Windsor, NY, USA) with an integrating sphere. Reflection values were recorded in the visible spectra range (360–750 nm) in increments of 10 nm. Measuring conditions were as follows: CIE L*a*b* color notation system, CIE D55 standard illuminant, 10° standard observer (CIE 1964 supplementary standard observer), specular component included, and very small area view 3 × 8 mm aperture. The spectrophotometer was calibrated using a black light trap and a white calibration tile, both provided by the manufacturer (GretagMacbeth LLC). Specimens were recorded against custom-made white and black polytetrafluoroethylene molds (white: L* = 66.3, a* = –1.30, b* = –4.03; black: L* = 24.5, a* = –0.01, b* = –0.43; 20 measurements). Accurate positioning of specimens was enabled by way of a custom jig.[4]

The total color difference was calculated as the sum of all color coordinate differences[24]:

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

The TP was calculated as the difference of color coordinate values obtained for the same specimen against black and white backgrounds[25]:

$$TP^* = [(L_B{}^* - L_W{}^*)^2 + (a_B{}^* - a_W{}^*)^2 + (b_B{}^* - b_W{}^*)^2]^{1/2}$$

where the subscript *B* refers to color coordinate values obtained against the black background and the subscript *W* is related to the values obtained against the white background.

ΔE* ≥ 3.7 was considered to be a poor match, and a total TP range was divided into three equal parts representing low, medium, and high translucency.

Aging-dependent TP changes (ΔTP) were calculated as the difference between TP values at certain intervals:

$$\Delta TP = TP_N - TP_M$$

where the subscript *N* is related to TP value obtained at baseline and the subscript *M* refers to TP at a certain aging interval (150, 300, or 450 kJ/m^2).

Means and SDs of L*, a*, b*, ΔE*, TP, and ΔTP were calculated. Analysis of variance was used for calculation of the *p* values, and Scheffé's *S* and Tukey-Kramer intervals for comparison of means of TP were calculated at the .05 level of significance (SuperANOVA®, Abacus Concepts, Berkeley, CA, USA).

RESULTS

Means and SDs of L* a* b* values at baseline as well as color difference metric values for each shade at baseline minus 450 kJ/m^2 (recorded against white background) are listed in Table 3. The ΔL* range at baseline was 26.1. Seven bleaching shades had lower lightness values compared to 3-D/1M2 and two were darker than XRV/B1 (see Table 1 for product and manufacturer information). The Δa* range at baseline was 3.4, and it was placed completely in the green part of coordinate a*. The Δb* at baseline range was 7.4, and it was placed in both blue and yellow parts of coordinate b*. The greatest changes for baseline minus 450 kJ/m^2 were recorded for the b* coordinate range, 8.3 for MH and 3.7 for MF. Corresponding values for L* and a* coordinate changes were 5.8 for MH and 0.9 for MF as well as 1.8 for MH and 1.2 for MF, respectively. Artificial aging, especially at the later stage, caused significant color change of microhybrids—mean ΔE* values at 150,

TABLE 3. MEAN L*a*b* VALUES AT BASELINE AND AGING-DEPENDENT ΔL*, Δa*, Δb*, AND ΔE* VALUES.[†]

Code	L* (SD)	a* (SD)	b* (SD)	ΔL* (SD)	Δa* (SD)	Δb* (SD)	ΔE* (SD)
Microhybrid							
3-D/EN2	60.0 (0.2)	−2.7 (0.0)	−2.4 (0.0)	1.1 (0.2)	0.3 (0.0)	−3.2 (0.2)	3.4 (0.2)
3-D/0M2	75.1 (0.6)	−2.2 (0.2)	0.1 (0.3)	1.3 (0.5)	0.4 (0.1)	−3.4 (0.5)	3.7 (0.4)
3-D/OP0M2	74.7 (0.2)	−1.7 (0.1)	1.2 (0.3)	0.5 (0.5)	0.3 (0.2)	−0.8 (1.1)	1.5 (0.4)
ES-X/W	72.6 (0.6)	−3.8[‡] (0.1)	−3.5 (0.1)	1.4 (0.5)	0.8 (0.1)	−3.9 (0.2)	4.2 (0.2)
ES-X/XL	65.3 (0.3)	−3.1 (0.0)	−4.1[‡] (0.2)	1.3 (0.4)	0.6 (0.0)	−3.2 (0.1)	3.5 (0.2)
TPH/BW	72.7 (0.3)	−3.0 (0.2)	−0.9 (0.1)	1.4 (0.2)	1.1 (0.3)	−4.6 (0.3)	4.9 (0.4)
TPH/XL	66.0 (0.5)	−1.9 (0.0)	0.4 (0.1)	−0.4 (0.3)	0.6 (0.0)	0.0[‡] (0.1)	0.7[‡] (0.2)
CH/SLO	70.4 (0.1)	−2.2 (0.1)	3.2 (0.3)	1.4 (0.2)	0.2 (0.1)	−4.1 (0.4)	4.3 (0.4)
CH/SLT	68.4 (0.1)	−1.7 (0.1)	3.3[‡] (0.1)	1.4 (0.4)	0.1 (0.2)	−3.5 (0.3)	3.8 (0.2)
CH/SL	72.9 (0.2)	−2.4 (0.2)	3.3 (0.3)	1.2 (0.2)	0.0 (0.3)	−3.8 (0.4)	4.0 (0.4)
P4/XL1	62.0 (0.3)	−2.6 (0.2)	−2.2 (0.2)	0.1 (0.4)	0.6 (0.2)	−2.0 (0.3)	2.2 (0.2)
P4/XL2	65.0 (0.2)	−2.9 (0.1)	−1.2 (0.1)	−0.1 (0.1)	0.6 (0.1)	−1.2 (0.6)	1.3 (0.4)
P4/XL3	75.3 (0.2)	−2.8 (0.1)	1.3 (0.1)	0.1 (0.1)	0.6 (0.2)	−2.2 (0.3)	2.3 (0.4)
Z250/B0.5	76.7 (0.2)	−2.8 (0.2)	−1.9 (0.1)	2.1 (0.3)	0.5 (0.2)	−1.1 (0.4)	2.4 (0.4)
TC/L	62.0 (0.3)	−3.1 (0.2)	−2.0 (0.1)	1.3 (0.3)	−0.6[‡] (0.2)	−3.6 (0.3)	3.9 (0.3)
TC/XL	77.3 (0.4)	−3.4 (0.1)	−0.6 (0.2)	1.5 (0.4)	−0.6[‡] (0.2)	−4.9 (0.6)	5.2 (0.6)
SYN/N	63.0 (0.4)	−3.3 (0.2)	−3.6 (0.2)	2.6 (0.3)	0.6 (0.2)	−7.0 (0.5)	7.5 (0.5)
SYN/O	73.3 (0.5)	−2.9 (0.2)	0.7 (0.1)	1.9 (0.5)	0.8 (0.2)	−8.3[‡] (0.6)	8.6[‡] (0.6)
SYN/P	63.8 (0.4)	−2.9 (0.0)	−1.1 (0.2)	1.4 (0.7)	0.8 (0.0)	−7.7 (0.5)	7.9 (0.6)
RU/SB1	74.4 (0.1)	−2.3 (0.1)	−1.5 (0.1)	1.9 (0.1)	0.2 (0.1)	−7.5 (0.3)	7.8 (0.2)
RU/SB2	72.9 (0.0)	−2.2 (0.1)	−1.2 (0.0)	2.0 (0.2)	0.1 (0.1)	−7.5 (0.1)	7.8 (0.1)
RU/SB3	71.1 (0.1)	−1.9 (0.0)	−0.9 (0.1)	2.0 (0.1)	0.2 (0.0)	−7.5 (0.2)	7.6 (0.2)
RN/B0	82.4[‡] (0.3)	−3.8[‡] (0.1)	1.8 (0.3)	1.9 (0.3)	0.2 (0.2)	−6.0 (0.2)	6.3 (0.3)
V/PF	59.5 (0.0)	−1.3 (0.0)	−0.9 (0.0)	5.0[‡] (0.6)	−0.5 (0.1)	−5.9 (0.4)	7.7 (0.4)
V/PA	56.3[‡] (0.0)	−0.4[‡] (0.0)	0.5 (0.0)	1.7 (1.2)	0.7 (0.0)	−4.1 (0.3)	4.6 (0.4)
V/PN	56.6 (0.0)	−0.9 (0.0)	−0.2 (0.0)	−0.8[‡] (1.3)	1.2[‡] (0.1)	−3.6 (0.3)	4.1 (0.4)
Microfill							
DF/SLO	62.1[‡] (0.1)	−2.3 (0.1)	1.1 (0.2)	0.2[‡] (0.2)	0.6 (0.1)	−1.9 (0.2)	2.0 (0.2)
DF/SSL	72.9 (0.3)	−2.1 (0.1)	0.3 (0.2)	0.6 (0.6)	0.6 (0.1)	−1.8 (0.4)	2.1 (0.5)
DF/SL	71.5 (0.1)	−2.8[‡] (0.0)	1.7 (0.2)	0.6 (0.2)	0.5 (0.0)	−2.5[‡] (0.3)	2.7[‡] (0.3)
A110/B0.5	77.8[‡] (0.0)	−2.5 (0.0)	−1.0 (0.0)	1.3[‡] (0.3)	1.3[‡] (0.2)	1.1[‡] (0.5)	2.2 (0.3)
RM/SB1	75.0 (0.0)	−2.4 (0.0)	−2.6 (0.0)	0.4 (0.1)	0.1[‡] (0.1)	−1.8 (0.3)	1.8 (0.3)
RM/SB2	73.3 (0.0)	−2.1 (0.0)	−2.9 (0.0)	0.6 (0.5)	0.2 (0.2)	−2.0 (0.2)	2.1 (0.3)
RM/SB3	72.3 (0.0)	−1.9[‡] (0.0)	−1.2 (0.0)	0.3 (0.4)	0.2 (0.1)	−1.6 (0.3)	1.7[‡] (0.2)
Control							
3-D/1M2	62.9 (0.0)	−0.8 (0.0)	2.9 (0.0)	0.6 (0.5)	0.3 (0.1)	−1.4 (0.5)	1.6 (0.6)
XRV/B1	58.2 (0.0)	−0.8 (0.0)	1.5 (0.0)	−0.6 (0.7)	1.9 (0.1)	0.8 (0.3)	2.2 (0.3)

[†] Baseline minus 450 kJ/m^2; white background. Scheffé's *S* intervals (p = .05) for comparisons of ΔL*, Δa*, Δb*, and ΔE* values of microhybrid composites for baseline minus 450 kJ/m^2 were 1.6, 0.6, 1.7, and 1.5, respectively. Corresponding Tukey-Kramer intervals for microfilled composites were 0.7, 0.3, 0.6, and 0.6, respectively.

[‡] Extreme color difference metric values.

300, 450 kJ/m^2 were 3.2, 4.0 and 4.7, respectively—and much smaller color changes of microfills—2.0, 2.0, and 2.1, respectively.

Means and SDs of TP at the baseline and ΔTP between baseline and 450 kJ/m^2 are listed in Table 4. TP values at baseline ranged from 0.9 to 4.3 for MH composites and from 1.4 to 2.2 for MF composites; TP values of control shades were within the range of bleaching shades. TP ranges at 150, 300, and 450 kJ/m^2 were 0.8 to 4.0 for MH composites and 0.9 to 2.0 for MF composites; 0.7 to 4.3 for MH composites and 1.5 to 2.0 for MF composites; 0.8 to 4.1 for MH composites and 0.9 to 2.4 for MF composites, respectively. Mean ΔTP values at 150, 300, and 450 kJ/m^2 were 0.07, 0.12, and 0.16 for MH composites and 0.14, 0.11, and 0.00 for MF composites, respectively.

TABLE 4. TP AT BASELINE AND AGING-DEPENDENT ΔTP.†

Code	TP (SD)	ΔTP (SD)
Microhybrid		
3-D/EN2	4.2 (0.2)	0.4 (0.1)
3-D/0M2	1.6 (0.3)	0.2 (0.3)
3-D/OP0M2	1.2 (0.1)	–0.4 (0.6)
ES-X/W	1.6 (0.2)	0.0 (0.3)
ES-X/XL	2.5 (0.3)	–0.1 (0.3)
TPH/BW	1.8 (0.2)	0.3 (0.3)
TPH/XL	2.1 (0.3)	0.0 (0.4)
CH/SLO	1.6 (0.2)	0.2 (0.3)
CH/SLT	1.9 (0.1)	0.2 (0.1)
CH/SL	1.4 (0.2)	0.2 (0.1)
P4/XL1	3.9 (0.3)	0.6 (0.5)
P4/XL2	2.7 (0.2)	0.3 (0.2)
P4/XL3	1.6 (0.6)	0.4 (0.7)
Z250/B0.5	1.2 (0.2)	0.2 (0.2)
TC/L	3.6 (0.3)	0.2 (0.3)
TC/XL	1.3 (0.2)	0.1 (0.1)
SYN/N	3.5 (0.2)	0.2 (0.2)
SYN/O	1.7 (0.4)	0.4 (0.4)
SYN/P	2.6 (0.2)	0.0 (0.4)
RU/SB1	1.2 (0.2)	–0.1 (0.1)
RU/SB2	1.7 (0.3)	0.3 (0.4)
RU/SB3	1.7 (0.1)	0.1 (0.2)
RN/B0	0.9‡ (0.1)	0.0 (0.2)
V/PA	3.0 (0.2)	–1.1‡ (0.4)
V/PN	4.2 (0.6)	0.4 (0.9)
V/PF	4.3‡ (0.6)	1.7‡ (0.7)
Microfilled		
DF/SLO	2.0 (0.2)	0.1 (0.1)
DF/SSL	1.4‡ (0.1)	0.2 (0.1)
DF/SL	2.2‡ (0.1)	0.1 (0.1)
A110/B0.5	1.0 (0.1)	0.2 (0.2)
RM/SB1	1.6 (0.2)	0.3‡ (0.2)
RM/SB2	1.8 (0.2)	–0.1‡ (0.3)
RM/SB3	1.9 (0.2)	0.0 (0.2)
Control		
3-D/1M2	2.7 (0.2)	0.1 (0.1)
XRV/B1	3.6 (0.2)	0.6 (0.3)

TP = translucency parameter.

†Baseline minus 450 kJ/m^2. Scheffé's S interval ($p = .05$) for comparisons of ΔTP values of microhybrid composites for baseline minus 450 kJ/m^2 was 1.0. The corresponding Tukey-Kramer interval for microfilled composites was 0.4.

‡Extreme color difference metric values.

DISCUSSION

In the context of durability of tested materials, correlation is the level of agreement between artificial weathering method and real-time service, whereas acceleration is a measure of how rapidly a test can be conducted compared with natural weathering. An American Society for Testing and Materials (ASTM) G151 standard defines factors that decrease correlation between accelerated aging tests using artificial light sources and real-time exposures. These factors are related to light, temperature, and humidity and include differences in spectral energy distribution and intensity of artificial light source, exposures to shorter wavelengths and a very strong emission in a narrow band spectra part, continuous light exposure with no dark periods, abnormally high temperatures and differences in temperature cycling conditions, and unrealistic levels of moisture.

According to ASTM G155, several cycles could be used for operating xenon-arc light apparatus for exposure of nonmetallic materials. The cycle used in this study is marked as CAM 180. It encompasses alternate exposure to light and darkness and intermittent exposure to water spray (simulates direct exposure with additional short wavelength energy).[26]

How many hours in an artificial test instrument equal 1 year in a patient's mouth? There is no published answer based on clinical findings to this logical and often-asked question. The manufacturer's estimation that 300 hours of aging is approximately equivalent to 1 year of clinical service should be used with extreme caution.[15,16] The variables mentioned above and differences among weathering devices and aging cycles influence the results and consequently the accuracy of estimation. A total exposure of 450 kJ/m^2 was equal to 345 hours or 115 aging cycles, which means that 100 hours in the aging chamber approximate 130 kJ/m^2. Since only the light hours should be counted and there were two light hours in each cycle, 150 kJ/m^2, 300 kJ/m^2, and 450 kJ/m^2 corresponded to 77, 153, and 230 light hours, respectively, which is in accordance with the literature.[15,16,22] The ratio between light hours and total hours in the aging chamber varies for different types of cycles. To avoid possible confusion, artificial aging should be expressed in kilojoules per square meter rather than in hours.

Aging-dependent L* a* b* differences at baseline minus 450 kJ/m^2 showed a characteristic lightness shift toward lower L* and a* values (23/26 MH shades and all MF shades), whereas b* values increased (the specimen became more saturated—25/26 MH shades and 6/7 MF shades), which is in accordance with the literature.[8–10] The magnitude of L*a*b* changes confirms better color stability of MF compared with that of MH composites. Aging-dependent changes showed synergistic effects with some curing-dependent color and TP changes and antagonistic effects with the other ones: MH composites become darker, less saturated, and more opaque, whereas MF composites became lighter, less saturated, and less opaque after light curing.[6]

At 450 kJ/m^2, 3 MH and 3 MF composites had a $\Delta E^* \leq 2.0$ relative to baseline, and 5 MH and 4 MF composites had a ΔE^* of 2.1 to 3.6, whereas 18 MH and no MF shades had a ΔE^* that was ≥ 3.7. These data underline the need for both improvement of long-term properties of some bleaching-shade composites and routine reexamination of related bleaching-shade restorations. Light shades of bleaching-shade composite resins originate from inorganic oxides added to match extralight tooth shades. The polymerization of visible light-cured composites occurs by their exposure to an intense blue light. Polymerization reaction starts with the light absorption by diketone in the presence of an organic amine.[5] Some initiators accelerate polymerization of composite resins, but they do not accelerate the aging process of once polymerized materials. With inorganic fillers, the higher the filler concentration, the better the color stability after aging; however, no strong correlation was found between the two parameters.[27] Changes of composite resins during clinical service occur because of stain accumulation, dehydration, water sorption, chemical breakdown, surface degradation, leakage, poor bonding, and surface roughness.[8,21] Similar changes were observed after artificial aging: crazing of surface and exposure of filler particles of conventional composites and crazing of MF composites, changes in the surface chemistry, weight loss per exposed surface area, and volume loss.[28] Color changes occurred as a consequence of some, if not all, of the mentioned physical (rougher surface texture increases the scattering of incident light) and chemical changes.[10]

TP generally decreased for both MH and MF composites; that is, the specimens became more opaque with aging. However, these changes were not perceptible. A wide range of TP values indicates the need for establishment of standardization in interpretation of results. Dividing of a TP range into three equal segments is one solution. A total of 15 MH and 6 MF shades were found to be of low translucency (0.9–2.0), 5 MH shades and 1 MF shade were of medium translucency (2.1–3.1), and 6 MH and no MF shades were highly translucent (3.2–4.3). Since color difference between black and white molds were lower compared with color difference between black and white calibration tiles used in the previous study,[6] TP values were generally lower.

The correlation of durability in terms of properties (eg, color, translucency, gloss, tensile strength) and chemical changes certainly requires additional research. However, relative comparison of the recorded data could be useful clinical guidelines for color stability evaluation of bleaching-shade composites and their relation to the conventional shades— the smaller the ΔE* value, the better the color stability. More recent color difference metric equations such as CMC (*l:c*), CIE 94, and CIE 2000 are in better accordance with visual findings than is CIE 76. Differences in color difference metric values among CIE 76 and mentioned advanced color notation systems could further complicate standardization and interpretation of the results of artificial aging experiments. The same applies to the absence of standardized values for white and black backgrounds in TP calculations. Although the relative ratio of the data recorded remained the same, some future standardization should also include standardized backgrounds (relative to their L*a*b* values). Lack of standardized specimen thickness and size as well as factors associated with differences in measuring device settings, design, and method are additional aspects that could compromise the comparison of results of artificial-aging experiments.

CONCLUSIONS

Accelerated aging generally caused decreases in L* (specimens became darker) and a* values (specimens become redder), whereas b* values increased (specimens became more saturated) for both MH and MF composites. Aging-dependent color changes at 450 kJ/m^2 were above the limit that indicated a poor match for 18 of 26 microhybrids. Corresponding ΔE* values of microfills were within acceptable range. Scheffé's *S* intervals ($p = .05$) for comparisons of ΔL*, Δa*, Δb*, and ΔE* values of MH composites for baseline minus 450 kJ/m^2 were 1.6, 0.6, 1.7, and 1.5, respectively. Corresponding Tukey-Kramer intervals for MF composites were 0.7, 0.3, 0.6, and 0.6, respectively.

TP values of the evaluated materials were highly varied. They generally decreased after aging (specimens became more opaque), but the difference was very small; TP was relatively stable during aging for both MH and MF composites. Scheffé's *S* interval ($p = .05$) for comparisons of ΔTP values of MH composites for baseline minus 450 kJ/m^2 was 1.0. The corresponding Tukey-Kramer interval for MF was 0.4.

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COMMENTARY

ACCELERATED AGING EFFECTS ON COLOR AND TRANSLUCENCY OF BLEACHING-SHADE COMPOSITES

Stephen C. Bayne, MS, PhD*

The authors of the above article adopted an excellent scientific approach toward investigating potential long-term changes in color of special bleaching-shade composites. Color research is not well understood by many clinical investigators and deserves some special comment. Clinically, color is visually assessed not simply as absolute color but as a color comparison to remaining tooth structure or other features of a patient's orofacial complex. It is quite possible that a composite restoration can change color and yet be undetected because the patient's teeth are undergoing normal dentin yellowing or darkening that maintains the color match. In a clinical trial of a restorative material, this would be rated as no change in color match. In laboratory experiments the same color change is detected. One should realize that laboratory-detected color changes may not always be important clinically.

Color is not an absolute quantity but, rather, depends on the (1) quality of light (wavelength and intensity), (2) character of the object being illuminated (surface roughness, surface staining, heterogeneity of the solid, phases involved, and sizes of the phases), and (3) observer (human being or instrument).[1,2] During the past couple of decades, color measurement has generally been detected as changes (from baseline) in terms of L*, a*, and b* values in the CIE system. The overall change in color (ΔE*) is determined from ΔL*, Δa*, and Δb* values. Although the equation may look complicated, it is simply the distance in three-dimensional color space between starting and ending values, calculated with the Pythagorean theorem:

$$d^2 = x^2 + y^2 + z^2$$

or

$$d = (x^2 + y^2 + z^2)^{1/2}$$

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