12. Doray PG, Li D, Powers JM. Color stability of provisional restorative materials after accelerated aging. J Prosthodont 2001; 10:212–216.

13. Doray PG, Wang X, Powers JM, Burgess JO. Accelerated aging affects color stability of provisional restorative materials. J Prosthodont 1997; 6:183–188.

14. Razzoog ME, Lang BR, Russell MM, May KB. A comparison of the color stability of conventional and titanium dental porcelain. J Prosthet Dent 1994; 72:453–456.

15. Douglas RD. Color stability of new-generation indirect resins for prosthodontic application. J Prosthet Dent 2000; 83:166–170.

16. Heydecke G, Zhang F, Razzoog ME. In vitro color stability of double-layer veneers after accelerated aging. J Prosthet Dent 2001; 85:551–557.

17. Powers JM, Fan PL. Color stability and aging of plastic veneering materials. J Dent Res 1981; 60:1692–1696.

18. Wang X, Powers JM, Conelly ME. Color stability of heat-activated and chemically activated fluid resin acrylics. J Prosthodont 1996; 5:266–269.

19. May KB, Shotwell JR, Koran A, Wang RF. Color stability: denture base resin processed with the microwave method. J Prosthet Dent 1996; 76:581–589.

20. Anil N, Hekimoglu C, Sahin S. Color stability of heat-polymerized and auto-polymerized soft denture liners. J Prosthet Dent 1999; 81:481–484.

21. Davis BA, Friedl KH, Powers JM. Color stability of hybrid ionomers after accelerated aging. J Prosthodont 1995; 4:111–115.

22. Noie F, O'Keefe KL, Powers JM. Color stability of resin cements after accelerated aging. Int J Prosthodont 1995; 8:51–55.

23. Hekimoglu C, Anil N, Etikan L. Effect of accelerated aging on the color stability of cemented laminate veneers. Int J Prosthodont 2000; 131:29–33.

24. Wyszecki G, Stiles WS. Color science. 2nd Ed. New York: John Wiley & Sons, 1982.

25. Rugh EH, Johnston WM, Hesse NS. The relationship between elastomer opacity, colorimeter beam size, and measured colorimetric response. Int J Prosthodont 1991; 4:569–576.

26. McGreer M. Atlas weathering testing guidebook. Chicago: Atlas Material Testing Technology LLC, 2001.

27. Setz J, Lin W, Pfeifer H. Color stability of light curing composites. Dtsch Zahnarztl Z 1990; 45:666–668.

28. Powers JM, Fan PL, Marcotte M. In vitro accelerated aging of composites and a sealant. J Dent Res 1981; 60:1672–1677.

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Reprint requests: Rade D. Paravina, DDS, MS, PhD, The University of Texas Dental Branch at Houston, 6516 M. D. Anderson Boulevard, Houston, TX, USA 77030-3402; e-mail: rparavina@uth.tmc.edu

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

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

**Professor, Operative Dentistry, UNC School of Dentistry, Chapel Hill, NC, USA*

As is emphasized by the authors of the present article, a $\Delta E^* \leq 2.0$ is considered clinically unimportant or undetectable, and $\Delta E^* \geq 3.7$ is considered a poor color match. Thus, changes detected in laboratory investigations of $\Delta E^* = 1.0$ to 2.0 may forecast a long-term trend but may not be ones that are of initial interest. Always be careful during interpretation of results.

In most cases investigators are focused on events related to the object (restorative material) being illuminated. It is worthwhile to reemphasize the many variables associated with the incident light. The surface is generally fabricated to be as smooth as possible. Rough surfaces scatter light and may not scatter all wavelengths in the same manner, affecting the color perceived by the observer. Also, rough surfaces are prone to stain collection during simulated or intraoral conditions. Coffee, tea, cola, and smoke stains variably absorb light and affect color. The practical smoothness of restorative materials depends to a large extent on the size of the dispersed phases. Large reinforcing particles are more often ripped from the surface during polishing operations, leaving the surface rougher than desired. Small particles may be similar in size to the wavelength of incoming light and diffract or scatter the light. Different methods of restorative coloration (organic stains or inorganic pigments) may be more or less stable. Polymer phases contain unterminated polymer chains, organic contaminants, residual initiators and accelerators, absorbed water or other intraoral materials such as esterases, and unreacted silane. As noted by the authors, some or all of these may contribute to future reactions causing color changes. At the same time, exposure to damaging ultraviolet radiation may cause polymer chain scission or produce other chemical reactions. Most polymer-based restorative materials contain ultraviolet light absorbers to protect against or discourage these reactions.

It is difficult to simulate all of these possible events, and most are therefore investigated individually or in highly controlled situations. A weatherometer is a device that simulates exposure to changing conditions of humidity, ultraviolet light, and heat over thousands of cycles. This is an excellent screen for initial color stability but still does not include many of the other suspected contributors mentioned above. Always be aware that any of the events may interact with others during the process of aging.

The most important observation of the authors was that significant color change occurred with many microhybrids ($\Delta E^* \geq 3.7$ for 18 microhybrids and no microfills) from the pool of 33 bleaching-shade composites. The tests in the weatherometer should not have contributed any superficial stains to the composite surfaces but might have affected the resistance to crazing of microhybrid surfaces differently than microfills. However, the change is most likely related to chemical differences between the two types of systems. Although they both may use a variety of monomer types, one might expect that the tendency of any system toward degradation would be more significantly affected by the original degree of conversion. If one assumes that conventional light shades permit good penetration of visible light for curing, then the degree of conversion should be in the range of 65%. However, as whitening is enhanced, the addition of reflective pigments may decrease the depth of cure and the degree of conversion by scattering more light. In addition, the average particle size of fillers in microhybrids tends to be in the range 0.5 μm (500 nm), which is about the same wavelength as visible light required for curing the system. Therefore, it is possible that this light is being scattered or diffracted by the particles. If the degree of conversion of microhybrids were only 55%, they would still provide reasonable clinical performance but would undergo discoloration reactions more easily.

Clearly we should continue to examine the changes uncovered by these authors, not only to improve the color stability of these systems but also to understand the underlying changes that are occurring.

REFERENCES

1. Sproul RC. Color matching in dentistry. Part 1. The three-dimensional nature of color. J Prosthet Dent 2001; 86:453–457.
2. Sproul RC. Color matching in dentistry. Part 2. Practical applications of the organization of color. J Prosthet Dent 2001; 86:458–464.