# Influence of Light-Curing Intensity on Color Stability and Microhardness of Composite Resins

*Henrico Badaoui Strazzi-Sahyon, DDS, MS*[1]
*Eduardo Passos Rocha, DDS, MS, PhD*[1]
*Wirley Gonçalves Assunção, DDS, MS, PhD*[1]
*Paulo Henrique dos Santos, DDS, MS, PhD*[1]

*The purpose of this study was to evaluate the intensity of light-curing units and its relationship with the color stability and microhardness of composite resins with different shades subjected to a thermocycling procedure. Eighty blocks (5.0 × 2.0 mm) of TPH Spectrum composite resin (Dentsply Sirona) were produced and distributed into four groups according to the light-curing units (EC 450, ECEL; Valo, Ultradent) and color of the resin material (A3; C3) (n = 20). Within each group, color stability was measured on half the sample (n = 10) using a UV-2450 visible UV spectrophotometer (Shimadzu), and Knoop hardness was measured on the other half (n = 10) using an HMV 2000 microhardness tester (Shimadzu) before and after thermocycling (12,000 cycles, 5°C and 55°C). Mann-Whitney test was performed on the color stability data; the microhardness data were analyzed using a three-way analysis of variance (ANOVA) and Tukey test (α = .05). The ANOVA results showed that thermocycling, distinct light intensity, and different colors of resin materials influenced the microhardness of the composite resins, which was evidenced by the A3 composite resin light-cured with a Valo polywave showing higher hardness values. There was no statistical difference in the color stability of the A3 composite resin; however, the C3 composite resin light-cured with an EC 450 singlewave light-curing unit showed higher color alteration values. In general, the Valo polywave light-curing unit imparted better mechanical property and color stability to both shades of the composite resins. The different shades of resin material influenced the hardness of the composite resins. Therefore, the light intensity of the light-curing units should be evaluated and monitored, as the amount of light intensity will interfere in the quality and longevity of resin restorations.*
Int J Periodontics Restorative Dent 2020;40:129–134. doi: 10.11607/prd.4437

[1]Department of Dental Materials and Prosthodontics, Araçatuba School of Dentistry, São Paulo State University (UNESP), Araçatuba – São Paulo, Brazil.

Correspondence to: Prof Paulo Henrique dos Santos, Department of Dental Materials and Prosthodontics, Araçatuba School of Dentistry – UNESP, Rua José Bonifácio, 1193, 16015-050 Araçatuba, SP-BRAZIL.
Fax: +5518 36363245. Email: paulo.santos@unesp.br

Submitted April 24, 2019; accepted July 31, 2019.


One of the most important advances in restorative procedures was the improvement of the method used for polymerization of resin materials. A high degree of composite polymerization is essential to ensure optimal physical and mechanical properties and compatibility with biologic structures.[1] For the light-curing materials, this is dependent on the correct application of the photopolymerizing light. The degree of conversion of a resin composite is defined as the percentage of reacted C=C bonds of the monomer molecules.[1] The residual unconverted methacrylate groups present a cytotoxic risk, and their solubility might cause the formation of microgaps and the occurrence of secondary caries, as well as wear resistance, color alteration, decreased mechanical proprieties, and an increased water sorption into the resin matrix.[1] The factors influencing the degree of conversion include the resin material composition,[2,3] as well as the shade and degree of translucency of these materials, type of photoinitiator,[4] type and power density of light-curing unit, curing time, light guide tip positioning, light wavelength, and light intensity.[5,6]

With technologic advancements, new versions of light-curing units have been introduced in dentistry, such as single-wave and polywave light-emitting diodes (LEDs), whose emission spectrum of the first generation is narrower than that of the halogen light-curing unit, with an emission spectrum similar to the spectrum of camphorquinone, the most-used photoinitiator in resin materials.[7–10] Single-wave and polywave light-curing units range from 2,000 up to 3,200 mW/cm$^2$; single-wave LEDs emit a single wavelength emission peak,[11] which is different than polywave units that emit a multiple-wavelength emission, polymerizing camphorquinone and other types of photoinitiators,[12] such as ivocerin and phenylpropanedione.[13] However, studies have shown that not all light-curing units in dental practices emit a sufficient intensity to ensure adequate polymerization of resin material. This unsatisfactory light intensity can be caused by various factors, such as contamination of the light guide, damage to the fiber optic bundle, reduced light output after repeated sterilizations, and dwindling battery power.[1]

This study aimed to evaluate the influence of different intensities of light-curing units and distinct shades of the composite resin on the color stability and microhardness of resin materials. The null hypotheses tested were that *(1)* the different intensities of light-curing units would not promote a significant difference in the color stability and microhardness of the composite resins; *(2)* the different shades would not influence the color stability and microhardness of resin materials; and *(3)* thermal aging would not cause a significant difference in the microhardness of the composite resins.

## Materials and Methods

### *Light-Intensity Measurement*

In this study, the light intensities of 40 light-curing units were measured. The study was approved by the Research and Ethics Committee of the Araçatuba School of Dentistry, São Paulo State University (#50715215.9.0000.5420). One calibrated examiner (H.B.S.S.) performed all measurements. An RD7 ECEL radiometer was used to measure the light intensity of light-curing units. The sensor in the radiometer determines the surface of the fiber optic tip on the polymerization unit as well as its light power. The irradiance is calculated by dividing the light power and surface of the light guide tip by the means of an integrated microprocessor. The measurements were performed by pressing the light guide directly onto the sensor and reading the irradiance values in mW/cm$^2$ from the screen at the start and after 40 seconds of illumination, which comprised one measurement. Three measurements were obtained for each light-curing unit, and subsequently, the arithmetic mean was calculated. The light-curing units that showed lower and higher values of light intensity were used for the experimental groups.

### *Specimen Preparation*

Eighty specimens were divided into four experimental groups (n = 20 per group) according to the shades of the composite resins and light-curing units.

Valo-A3 Group: Twenty A3-shade microhybrid TPH Spectrum (Dentsply Sirona) resin blocks were produced using a metallic matrix (5.0-mm diameter, 2.0-mm thickness). The composite resin was inserted using a Thompson spatula (Quinelato). The resin was covered with a transparent polyester filmstrip and a glass microscope slide to flatten the material and prevent bubble formation. Finally, the samples were light cured using a Valo polywave light-curing unit (Ultradent), 1,431 mW/cm$^2$ for 40 seconds.

Valo-C3 Group: In this group, the same procedure was performed as described for the previous group; however, the C3 shade TPH composite resin (Dentsply Sirona) was used.

EC 450-A3 Group: In this group, the same procedure was performed as reported for the first group; however, the photoactivation of the composite resin was performed using the EC 450 single-wave light-curing unit (ECEL) with a light intensity of 101 mW/cm$^2$ for 40 seconds.

EC 450-C3 Group: In this group, the same procedure was performed as described for the previous group; however, the C3 shade TPH composite resin (Dentsply Sirona) was used.

All samples were stored in 37°C for 24 hours in light-protected containers. Forty specimens were separated to evaluate the color stability (n = 10 per group), and forty were used to analyze the microhardness (n = 10 per group).

### Color Stability Analysis

The baseline color was measured according to the CIELab (Commission Internationale de l'Eclairage) color system using a reflectance spectrophotometer (UV-2450, Shimadzu) over a white background and standard illuminant D65. The CIELab color space graph is a three-dimensional color measurement. The parameter L refers to the lightness coordinate, and its value ranges from 0 (perfect black) to 100 (perfect white). The parameters a and b are chromaticity coordinates on the green-red (–a = green; +a = red) and blue-yellow (–b = blue; +b = yellow) axes. Five color analysis readings were performed for each sample, and the arithmetic mean of the values were calculated.

After the baseline color measurement, the specimens were subjected to a thermocycling procedure (5°C and 55°C, 12,000 cycles, 30 seconds each) in an MSTC-3 Plus Thermal Cycling Machine (ElQuip).[14] After thermal aging, a new color measurement was performed using the same method previously described. The color difference after aging was calculated between the color coordinates before (baseline) and after the aging process, as measured in the reflectance mode by applying the formula: $\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$, where ΔE is the color difference; $\Delta L^*$ is $L_{after\ aging} - L_{baseline}$; $\Delta a^*$ is $a_{after\ aging} - a_{baseline}$, and $\Delta b^*$ is $b_{after\ aging} - b_{baseline}$.[15]

The specimens were stored in distilled water at 37°C until color reading was performed on all samples.

**Table 1 Mean of Color-Change Values (ΔE ± Standard Deviation) per Group**

| Light-curing unit | Composite resin shade: A3 | Composite resin shade: C3 |
|---|---|---|
| Valo | $3.3 \pm 1.1^{Aa}$ | $3.1 \pm 2.1^{Ba}$ |
| EC 450 | $3.1 \pm 3.0^{Aa}$ | $4.3 \pm 2.2^{Aa}$ |

Uppercase (columns) and lowercase (rows) superscript letters indicate statistically significant differences ($P < .05$).

### Microhardness Analysis

The Knoop microhardness measurements were performed using an HMV 2,000 microhardness tester (Shimadzu) on the top of the resin samples. Five indentations were created 1 mm from each other for each specimen under a static load of 25 g for 5 seconds, and the arithmetic mean of the values was calculated.[16,17] The Knoop hardness values were assessed by CAMS_WIN program (Newage Testing Instruments). After the baseline microhardness measurement, the specimens were subjected to the thermocycling procedure as described for the above analysis. After thermal aging, the Knoop microhardness (KHN) measurements were performed using the same method as described above.

### Statistical Analysis

Statistical analyses were performed using Mann-Whitney test for the color stability analysis, and three-way repeated-measures analysis of variance (ANOVA) followed by Tukey protected least significant difference test ($\alpha = .05$) were used for the microhardness analysis.

## Results

As shown in Table 1, there was no significant difference in chromatic stability of the composite-resin shades light cured with both light-curing units ($P > .05$). The C3 composite resin activated with the Valo polywave showed a lower color alteration than with the EC 450 single-wave light curing unit ($P = .0412$). However, there was no significant difference between the different light-curing units used for the A3 composite resin ($P = .7055$) (Table 1).

The ANOVA microhardness analysis indicated that thermal aging was able to decrease the hardness for both shades of the resin material polymerized with both light-curing units ($P < .05$) (Table 2). Comparing the composite-resin shades, there was no statistical difference when the A3 and C3 composite resins were activated with Valo ($P > .05$). However, when these materials were activated with the EC 450 single-wave unit, the A3 shade showed higher microhardness values than those of the C3 composite resin before and after thermocycling ($P < .05$). In relation to the light-curing units, the samples polymerized with the Valo polywave showed higher microhardness

**Table 2 Mean ± SD Values of Knoop Microhardness of Composite Resins**

| Light-curing unit | Composite resin shade | Before thermal aging | After thermal aging |
|---|---|---|---|
| Valo | A3 | 99.3 ± 8.7$^{AaA}$ | 85.5 ± 6.9$^{AbA}$ |
| Valo | C3 | 91.8 ± 8.7$^{AaA}$ | 80.5 ± 6.5$^{AbA}$ |
| EC 450 | A3 | 54.6 ± 7.8$^{AaB}$ | 47.2 ± 11.6$^{AbB}$ |
| EC 450 | C3 | 41.8 ± 9.5$^{BaB}$ | 33.5 ± 4.9$^{BbB}$ |

SD = standard deviation.
First uppercase (columns), lowercase (rows), and second uppercase (comparison between light-curing units for the same experimental condition) superscript letters indicate statistically significant differences ($P < .05$).

values than those of the EC 450 single-wave unit ($P < .05$).

## Discussion

Proper functioning and an adequate intensity of the light-curing units are essential for the longevity and satisfactory physical, chemical, and mechanical properties of the resin materials. The results showed that the different light intensities influenced the color stability and microhardness of the composite resin. In addition, the use of different shades of resin material caused a significant difference in the Knoop hardness values, thus rejecting the first and second null hypotheses of this study. Thermal aging also influenced the microhardness of the resin material, rejecting the third null hypothesis.

Previous studies reported that the minimum light intensity required for adequate polymerization of 2 mm of resin composite was approximately 400 mW/cm$^2$ with an exposure time of 40 seconds.[5,18] However, the EC 450 light-curing unit showed lower light intensity values than those of the manufacturer product specifications. Insufficiently polymerized resin material may present numerous problems, such as chemical degradation, poor color stability, and water sorption.[19–21]

The color stability analysis is one of the most-used tests for determining the clinical success and longevity of restorative procedures. The test is capable of detecting a chromatic alteration due to the inefficiency polymerization of the resin materials,[22] as observed in the EC 450-C3 group, which showed clinically perceptible changes (Table 1) because ΔE was higher than 3.3, which is considered perceptible to the human eye. For this group, the lower light intensity and darker shade of the resin material contributed negatively to a higher color alteration of the resin matrix. After water immersion, the uncured monomers could be eliminated from the bulk of the material, leading to free spaces that could be filled by water, producing hydrolysis of the resin matrix that affected the optical properties of the resin materials.[22]

According to Ozcan et al,[23] thermocycling is more effective than other methods for simulating the aging of composites and creating more challenging conditions for composite restorations.[23,24] Thermocycling is performed to create thermal stress by thermal changes in water (5°C to 55°C), justifying the difference in the microhardness values before and after thermocycling (Table 2). The repetition of the thermal alterations in this process weakens the bonding interface between the resin matrix and filler content via the degradation and water sorption into the resin matrix.[23]

According to Strazzi Sahyon et al,[25] the water incorporation into the resin material directly impacts the clinical behavior of dental materials, which could promote irreversible damages, such as microcracks and hydrolytic degradation of the chemical compounds of the resin material.[25] The nonsatisfactory polymerization of the monomers could release the uncured monomers to the aqueous medium, promoting a microspace into the resin matrix, decreasing the mechanical properties and promoting color alteration of the resin material.[23,24]

The advantage of the Knoop hardness test of the resin materials is the correlation between the hardness and degree of monomer conversion.[21] The mechanical properties of the resin materials are directly influenced by the degree of conversion. Adequate polymerization is a fundamental factor for obtaining an optimal physical mechanical performance of the composite resins. Various factors, such as the filler and polymeric matrix refractive index, monomer type, filler type, and filler content, can interfere with the light transmittance of the composite resin.[21]

In a previous study, Reges et al reported significantly lower Knoop hardness values for a darker resin material than for other, lighter shades.[26] The selected shades differed substantially in light-transmission properties. The diversity in the shade of the composite resin was expected to affect the polymerization extent and mechanical properties of the cured material.[27] Therefore, the loss of energy could be related to the light absorption by the resin matrix and the light dispersion by the composite resin filler and opacifiers, attenuating the light intensity and its effectiveness of the monomer polymerization as depth increases.[21] The pigments in darker shades of resin-based materials might absorb light, reducing its penetration along the depth of the restorative material.[26] A greater intensity of light energy and/or lengthy duration could be considered to excite the camphorquinone in the darker resin materials,[28] obtaining a similar polymerization potential as that of the lighter shades.[25]

Thus, based on the results of this study, light intensity is a relevant factor in the polymerization of resin materials, influencing the chromatic stability and hardness of these composites. Clinically, in order to ensure the quality and longevity of the restorations, it is essential to use light-curing units with stable light intensity, monitoring it by using radiometry or manufacturers' light-intensity indicators during the lifetime of the light-curing units. Some factors could influence the power density and affect the resin-based materials properties, including possible contamination and several sterilizations of the light guide, dwindling battery power, distance of the light guide to the restoration, and composition of the material itself.[1,28]

Some limiting factors of this study should be considered, such as the use of only one composite resin. Because this was an in vitro study, the relationship between the results at the laboratory level to those of the clinical condition should be evaluated, as the in vitro studies cannot simulate the actual condition of the oral cavity. Therefore, future studies are required to inform professionals to frequently monitor the intensity of the light-curing unit in order to promote satisfactory oral rehabilitations.

## Conclusions

Based on the methodology and results obtained in this study, it can be concluded that the Valo polywave light-curing unit provided better color stability and microhardness of the composite resins compared to EC 450 single-wave light-curing unit. The C3 shade showed lower hardness values than the A3 shade when polymerized with EC 450 light-curing unit. Thermocycling was able to decrease the hardness for both shades of the resin material polymerized with both light-curing units. The regular evaluation of the intensity of light-curing units is recommended in order to ensure the quality and longevity of resin restorations.

## Acknowledgments

The authors declare no conflicts of interest.

## References

1. Tongtaksin A, Leevailoj C. Battery charge affects the stability of light intensity from light-emitting diode light-curing units. Oper Dent 2017;42:497–504.
2. Sideridou I, Tserki V, Papanastasiou G. Effect of chemical structure on degree of conversion in light-cured dimethacrylate-based dental resins. Biomaterials 2002;23:1819–1829.
3. Halvorson RH, Erickson RL, Davidson CL. The effect of filler and silane content on conversion of resin-based composite. Dent Mater 2003;19:327–333.
4. Musanje L, Ferracane JL, Sakaguchi RL. Determination of the optimal photoinitiator concentration in dental composites based on essential material properties. Dent Mater 2009;25:994–1000.
5. Alkhudhairy F. Wear resistance of bulk-fill composite resin restorative materials polymerized under different curing intensities. J Contemp Dent Pract 2017;18:39–43.
6. Price RB, Whalen JM, Price TB, Felix CM, Fahey J. The effect of specimen temperature on the polymerization of a resin-composite. Dent Mater 2011;27:983–989.
7. Schneider LF, Pfeifer CS, Consani S, Prahl SA, Ferracane JL. Influence of photoinitiator type on the rate of polymerization, degree of conversion, hardness and yellowing of dental resin composites. Dent Mater 2008;24:1169–1177.
8. AlQahtani MQ, AlShaafi MM, Price RB. Effects of single-peak vs polywave light-emitting diode curing lights on the polymerization of resin cement. J Adhes Dent 2013;15:547–551.
9. Lovell LG, Lu H, Elliott JE, Stansbury JW, Bowman CN. The effect of cure rate on the mechanical properties of dental resins. Dent Mater 2001;17:504–511.

10. Schneider LF, Cavalcante LM, Prahl SA, Pfeifer CS, Ferracane JL. Curing efficiency of dental resin composites formulated with camphorquinone or trimethylbenzoyl-diphenyl-phosphine oxide. Dent Mater 2012;28:392–397.
11. Jung H, Friedl KH, Hiller KA, Furch H, Bernhart S, Schmalz G. Polymerization efficiency of different photocuring units through ceramic discs. Oper Dent 2006;31:68–77.
12. Watanabe H, Kazama R, Asai T, et al. Efficiency of dual-cured resin cement polymerization induced by high-intensity LED curing units through ceramic material. Oper Dent 2015;40:153–162.
13. Sun GJ, Chae KH. Properties of 2,3-butanedione and 1-phenyl-1,2-propanedione as new photosensitizers for visible light cured dental resin composites. Polymer 2000;41:6205–6212.
14. Moda MD, Godas AGL, Fernandes JC, et al. Comparison of different polishing methods on the surface roughness of microhybrid, microfill, and nanofill composite resins. J Investig Clin Dent 2018. Epub ahead of print.
15. Catelan A, Suzuki TYU, Becker F Jr, Briso ALF, Dos Santos PH. Influence of surface sealing on color stability and roughness of composite submitted to ultraviolet-accelerated aging. J Investig Clin Dent 2017. Epub ahead of print.
16. Sahyon HBS, Guedes APA, Godas AGL, Suzuki TYU, Briso ALF, Dos Santos PH. Effect of fluoride-releasing adhesive systems in control of dental enamel hardness subjected to acid challenge. Arch Health Invest 2017;6:192–196.
17. Borges GA, Agarwal P, Miranzi BA, Platt JA, Valentino TA, dos Santos PH. Influence of different ceramics on resin cement Knoop Hardness Number. Oper Dent 2008;33:622–628.
18. Rueggeberg FA, Caughman WF, Curtis JW Jr. Effect of light intensity and exposure duration on cure of resin composite. Oper Dent 1994;19:26–32.
19. Fonseca AS, Labruna Moreira AD, de Albuquerque PP, de Menezes LR, Pfeifer CS, Schneider LF. Effect of monomer type on the CC degree of conversion, water sorption and solubility, and color stability of model dental composites. Dent Mater 2017;33:394–401.
20. Oliveira DC, Souza-Júnior EJ, Prieto LT, Coppini EK, Maia RR, Paulillo LA. Color stability and polymerization behavior of direct esthetic restorations. J Esthet Restor Dent 2014;26:288–295.
21. Guiraldo RD, Consani S, Consani RL, Berger SB, Mendes WB, Sinhoreti MA. Light energy transmission through composite influenced by material shades. Bull Tokyo Dent Coll 2009;50:183–190.
22. Sedrez-Porto JA, Münchow EA, Cenci MS, Pereira-Cenci T. Translucency and color stability of resin composite and dental adhesives as modeling liquids—A one-year evaluation. Braz Oral Res 2017;31:e54.
23. Ozcan M, Barbosa SH, Melo RM, Galhano GA, Bottino MA. Effect of surface conditioning methods on the microtensile bond strength of resin composite to composite after aging conditions. Dent Mater 2007;23:1276–1282.
24. Kiomarsi N, Saburian P, Chiniforush N, Karazifard MJ, Hashemikamangar SS. Effect of thermocycling and surface treatment on repair bond strength of composite. J Clin Exp Dent 2017;9:e945–e951.
25. Strazzi Sahyon HB, Chimanski A, Yoshimura HN, Dos Santos PH. Effect of previous photoactivation of the adhesive system on the color stability and mechanical properties of resin components in ceramic laminate veneer luting. J Prosthet Dent 2018;120:631.
26. Reges RV, Costa AR, Correr AB, et al. Effect of light-curing units, post-cured time and shade of resin cement on Knoop Hardness. Braz Dent J 2009;20:410–413.
27. Juloski J, Goracci C, Tsintsadze N, et al. Influence of luting agent translucency on fiber post retention. Eur J Oral Sci 2015;123:116–121.
28. Tanthanuch S, Kukiattrakoon B. The effect of curing time by conventional quartz tungsten halogens and new light-emitting diodes light curing units on degree of conversion and microhardness of a nanohybrid resin composite. J Conserv Dent 2019;22:196–200.