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Abstract

Introduction: The purpose of this study was to compare the percentage degree of cure (%DC) of orthodontic adhesive resins irradiated with 3 types of light sources of various intensities: plasma arc, halogen, and light-emitting diode (LED). **Methods:** Twenty maxillary incisor stainless steel brackets (0.018-in slot) were divided into 4 groups of 5 brackets each. A standardized amount of composite resin was applied to each bracket base, simulating its clinical application. The brackets were light-cured with a halogen light for 20 seconds (10 seconds each from the incisal and cervical bracket edges), an LED light for 20 seconds (10 seconds per edge), a plasma light for 10 seconds (5 seconds per edge), and an LED light for 10 seconds (5 seconds per edge). The %DC was assessed by using micro-multiple internal reflectance Fourier transform infrared spectroscopy, and the results were analyzed with 1-way ANOVA. **Results:** Overall, the LED and the halogen lights, with the 20-second regimen, produced higher %DC. No significant difference was found in %DC between the plasma light and the 10-second LED light, whereas both showed lower %DC compared with 20 seconds of halogen or LED light. **Conclusions:** Significant variations in %DC are associated with the various light-curing units, which must be considered in selecting the light source and the irradiation time.

Light-cured orthodontic adhesives require a light-curing source with sufficient intensity and defined wavelength to initiate the polymerization reaction.[1] Increased light intensity and curing time have been advocated for fast polymerization and high degree of cure.[2, 3] Camphoroquinone (CQ), a photoinitiator used in most resin composites, has an absorption spectrum of 410 to 490 nm, with a peak at 468 nm.[1, 4] When CQ is exposed to light in the presence of a reducing amine, radicals are formed that initiate polymerization.

Recently, various types of commercially available light-curing units have shown comparable bond strength values to that of conventional halogen lights at shorter irradiation times.[5] Although much of the relevant literature deals with the variation of bond strength as a function of the light-curing unit, no information has been presented on the effect of various irradiation sources on the degree of cure (DC) of the resin phase. This factor cannot be elucidated by simple bond strength tests and is of paramount importance because it modulates the mechanical, physical, and biologic properties of the resin adhesive.

The purpose of this study was to compare the percent DC (%DC) of a resin composite orthodontic adhesive by using 3 types of light sources with various light intensities: plasma arc, halogen, and light-emitting diode (LED). The hypothesis tested was that the different types of light-curing sources, when used for the recommended irradiation times, result in different %DC.

Material and methods

Twenty stainless steel maxillary incisor brackets (Ormco, Glendora, Calif), with 0.018-in slot, were divided into 4 groups (groups A-D) of 5 brackets each. A standardized amount (about 10 mg), determined after a pilot trial, of a light-cured adhesive (Eagle Spectrum, American Orthodontics, Sheboygan, Wis) was applied to each bracket base, which was then firmly pressed against a flat polystyrene strip with a yellowish background of 75% diffuse reflectance to simulate enamel backing reflectance. Excess resin was removed before polymerization. Resin polymerization for all groups was performed by irradiation from the incisal and cervical directions at a 45° angle facing the corresponding bracket edges at 37° ± 1°C and 50% relative humidity. Polymerization conditions are described in Table I. Immediately after polymerization, the polystyrene strips were removed, and the flat surfaces of the cured resin specimens were pressed firmly to a KRS-5 minicrystal of a micro-multiple internal reflection accessory (Perkin Elmer, Norwalk, Conn) attached to a Fourier transform infrared spectrometer (Spectrum GX, Perkin Elmer). Spectra were obtained under the following conditions: 4000 to 400 cm^{-1} wave number range, 4 cm^{-1} resolution, 30 scans coaddition, about 3 µm depth of analysis at 1000 cm^{-1}. Reference spectra were obtained from 5 samples of the unpolymerized adhesive. The %DC of the set specimens relative to the uncured control was assessed based on the 2-frequency method and the tangent baseline technique.[6] The aliphatic (C=C) bond-stretching vibrations at 1636 cm^{-1} were chosen as the analytical frequency, whereas the aromatic (C..C) bond-stretching vibrations at 1609 cm^{-1}, which are not affected by polymerization, were selected as the reference frequency.[7]

Table I. Curing conditions tested

Group	Curing conditions
A	20 s (10 s each direction), halogen unit @ 800 mW/cm^2 (Trilight, 3M ESPE, Seefeld, Germany)
B	20 s (10 s each direction), LED unit @1100 mW/cm^2 (TC-100-2, The Cure, Spring Health Products, Norristown, Penna)
C	10 s (5 s each direction), plasma-arc unit @ 2040 mW/cm^2 (Virtuoso, Den-Mat, Santa Maria, Calif)
D	10 s (5 s each direction), LED unit @1100 mW/cm^2 (TC-100-2, The Cure, Spring Health Products)

Statistical analyses were performed with analysis of variance (ANOVA) and the Tukey test ($\alpha = 0.05$).

Results

The results of the %DC for the groups tested are given in Table II. The halogen and the LED sources, when used with the 20-second regimen, produced the highest %DC with no statistically significant difference between them. No statistically significant difference was found between the %DC mean values of the plasma and the LED sources after 10-second irradiation times, whereas both showed significantly lower %DC after the 20-second irradiation times with the halogen or the LED sources.

Table II. Summary statistics for %DC by light source and results from pair-wise comparisons

Group	Mean	SD	Tukey grouping*
A	48.35	1.87	A
B	46.16	1.92	A
C	35.35	1.87	B
D	32.34	6.54	B

∗Means with different letters are significantly different ($P<.05$).

Discussion

The use of micro-multiple internal reflection Fourier transform infrared spectroscopy has been advocated as an appropriate analytical technique in quantifying C=C conversion of resin composites.1, 8 Orthodontic bonding involves adhesives firmly pressed between enamel and a bracket base, leading to material layers of no more than 250 µm in thickness.[9] In simulating clinical conditions, the artificial background surface resulted in exclusion of the effects of variability in optical properties and topography of the bonding surface on the %DC, as would have occurred with bonding to enamel surfaces.[10, 11]

The curing units in this study had various intensities and curing times with no evidence of their influence on the DC. An important parameter of curing units is the amount of light energy emitted and the appropriate wavelength to efficiently excite the photoinitiator.[1] Nomoto[4] suggested that, in the 490 to 450 nm wavelength range, light intensity and exposure time are more significant than light wavelength in determining the DC, since CQ exhibits a broad absorption spectrum at this range. Curing time has been directly associated with increased conversion in a study comparing high- and low-intensity halogen lights.[12] Nevertheless, an LED light with a lower intensity than a halogen light has been shown to produce greater depth of cure,[13] implying a complicated interaction pattern of light intensity, emitted wavelength, curing time, and material absorptivity.

The spectrum emitted by most LED and plasma-arc curing units has a narrow bandwidth of about 470 nm, where the absorption maxima of CQ lies. However, in some resin composites, other types of photoinitiators are used that absorb at different wavelengths; ie, phenyl propanodione, which possesses a λ_{max} of 410 nm, rendering the use of these units inadequate for effective curing. In our study, the orthodontic adhesive contained CQ as the photoinitiator, which is compatible with the emitted wavelengths from all light sources selected.

Reduction of curing time with high-intensity curing units was initially advocated for restorative resin composites to reduce chair-side time. However, questions have been raised about the efficacy of the high irradiance emitted in a short time, especially by plasma-arc sources, to achieve adequate polymerization. It has been shown that composites cured by plasma-arc curing units for 7 seconds provided lower %DC compared with halogen lights used for 40 seconds,[14] highlighting the critical role of the total emitted light energy concept in the extent of photopolymerization. In this study, the total energy emitted per unit area (J/cm^2) was calculated as 16 (group A), 22 (group B), 20.4 (group C), and 11 (group D), a ranking that does not match the %DC. A possible explanation might be the irradiation geometry of a 45° incidence angle from the cervical and incisal directions. For example, the size of the irradiation tip might affect the radiant flux density reaching the adhesive resin at the margins and, therefore, the resultant light-scattering effects related to in-depth curing.

In addition, the variation of %DC as a function of bond strength has not been examined, and it is possible that the latter is unaffected after a certain %DC is reached. The %DC, a material variable, is largely unaffected by environmental conditions and is not a derivative of a constructed test such as bond strength, which involves many assumptions.[15] Moreover, bond strength is a poor indicator of %DC because of the interference of bracket design and variations in load application, loading rates, teeth storage and preparation, and testing conditions, among other factors. On the contrary, %DC has been shown to modulate the mechanical properties of the material[16, 17] as well as the resistance to degradation and dissolution,[18] a key property that cannot be explored with bond strength tests. This factor might explain the apparent discrepancy between bond strength studies (which indicate acceptable bond strength values) and failure rates (which show increased frequency of bond loss).

The results of this study show a rather complex interaction pathway between light-cured adhesives used for metallic bracket bonding and the various types of light-curing units.

Conclusions

1The Trilight halogen (3M ESPE, Seefeld, Germany) and the Cure LED (Spring Health Products, Norristown, Penna) lights produced similar %DC when used for the same amount of cure time.

2Polymerization with the Virtuoso plasma (Den-Mat, Santa Maria, Calif) and the Cure LED lights for 10 seconds produced decreased %DC relative to the Trilight halogen or the Cure LED units with 20-second cure times.

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